Nucleus

By : J K Nath (Asst Professor)

The nucleus :

The nucleus is the controlling centre of the eukaryotic cell. The presence of a nucleus is the principal feature that distinguishes eukaryotic from prokaryotic cells. By housing the cell's genome, the nucleus serves both as the repository of genetic information and as the cell's control center. DNA replication, transcription, and RNA processing all take place within the nucleus, with only the final stage of gene expression (translation) localized to the cytoplasm. A nucleus in G_0 stage has four components : **Nuclear envelope, nucleolus, nuclear matrix and chromatins.**

By separating the genome from the cytoplasm, the nuclear envelope allows gene expression to be regulated by mechanisms that are unique to eukaryotes. By limiting the access of selected proteins to the genetic material, the nuclear envelope also provides novel opportunities for the control of gene expression at the level of transcription. For example, the expression of some eukaryotic genes is controlled by the regulated transport of transcription factors from the cytoplasm to the nucleus—a form of transcriptional regulation unavailable to prokaryotes.

Nuclear envelop :

The nuclear envelope consists of two concentric membranes called the **inner** and **outer** nuclear membranes. The outer nuclear membrane is continuous with the endoplasmic reticulum, so the space between the inner and outer nuclear membranes, the **perinuclear space**, is directly connected with the lumen of the endoplasmic reticulum. In addition, the outer nuclear membrane is functionally similar to the membranes of the endoplasmic reticulum and has ribosomes bound to its cytoplasmic surface. In contrast, the inner nuclear membrane carries unique proteins that are specific to the nucleus. The critical function of the nuclear membrane is to act as a barrier that separates the contents of the nucleus from the cytoplasm. The nuclear envelope contains nuclear pores for transport of macromolecules between the cytoplasm and nucleus.

The nuclear matrix is a network of protein filaments in the nucleus which provides a structural framework for organizing chromatin, while facilitating transcription and replication. Underlying the inner nuclear membrane is the **nuclear lamina**, a filamentous meshwork that provides structural support to the nucleus. The nuclear

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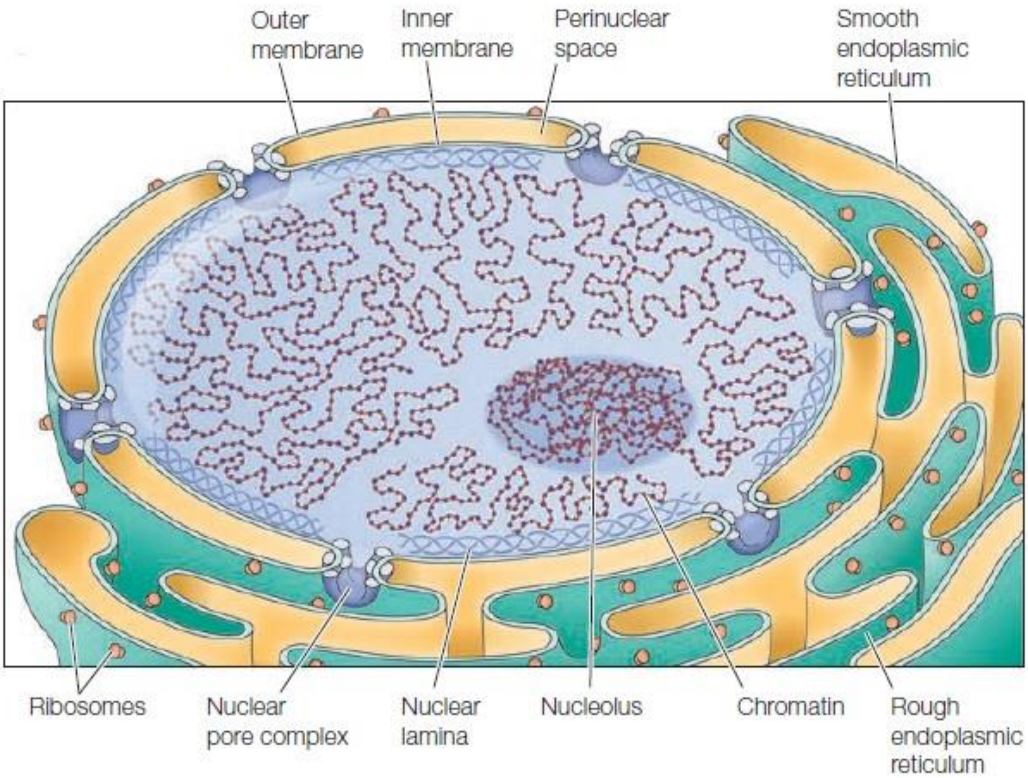
lamina is composed of 60- to 80-kilodalton (kd) fibrous proteins called lamins, along with associated proteins. Lamins are a class of intermediate filament proteins.

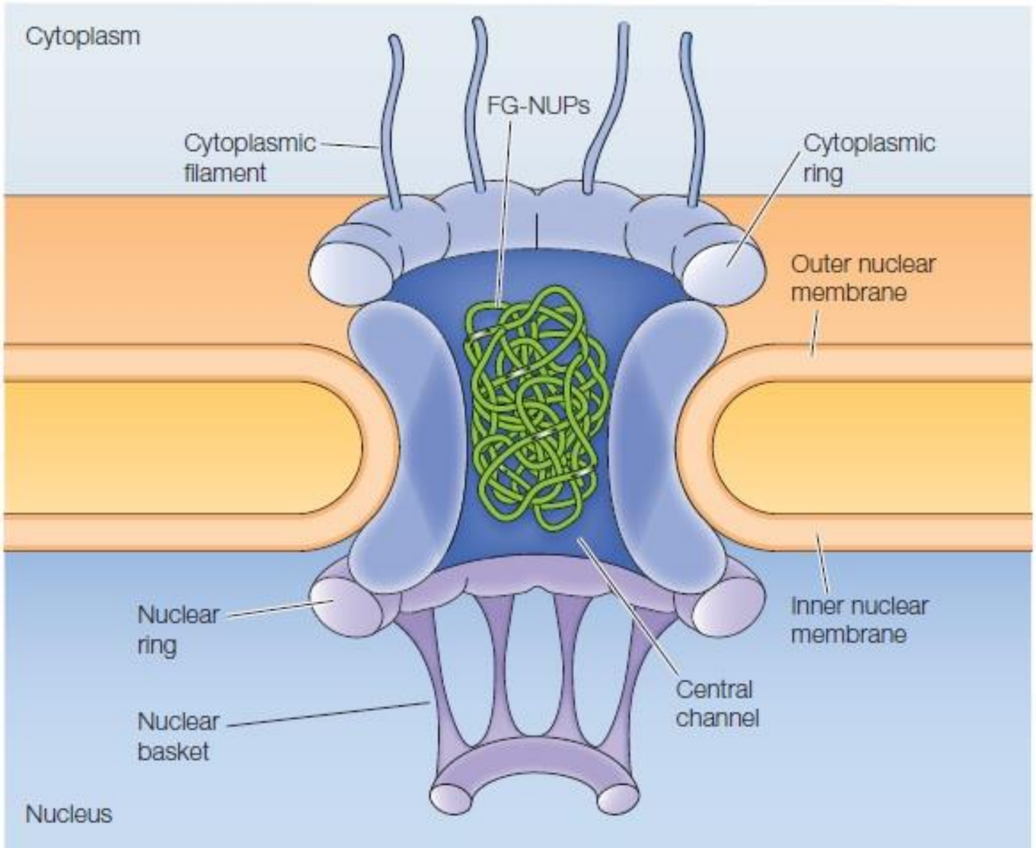


The nuclear pore complex(NPC) :

The nuclear pore complexes are the only channels through which small polar molecules, ions, and macromolecules (proteins and RNAs) can travel between the nucleus and the cytoplasm. The nuclear pore complex is an extremely large structure with a molecular mass of approximately 120 million daltons in humans—about 30 times the size of a ribosome. In vertebrates the nuclear pore complex is composed of multiple copies of about 30 different pore proteins (called nucleoporins or NUPs). By controlling the traffic of molecules between the nucleus and the cytoplasm, the nuclear pore complex plays a fundamental role in the physiology of all eukaryotic cells. RNAs synthesized in the nucleus must be efficiently exported to the cytoplasm where they function in protein synthesis. Conversely, proteins required for nuclear functions must be transported to the nucleus from their sites of synthesis in the cytoplasm.

Detailed structural studies have led to the development of three-dimensional models of the nuclear pore complex. These studies show that the nuclear pore complex consists of an assembly of eight spokes arranged around a central channel. The spokes are connected to rings at the nuclear and cytoplasmic surfaces. Protein filaments extend from both the cytoplasmic and nuclear rings, forming a distinct basket like structure on the nuclear side.

The central channel is lined by proteins called FG-NUPs because they contain repeats that are rich in **phenylanine and glycine** residues. The FG-NUPs are the barrier to permeability of the pore and facilitate regulated transport between the nucleus and the cytoplasm.



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Nuclear Matrix or Nucleoplasm :

Nucleoplasm, also known as nuclear sap or karyoplasm, is the viscous, jelly-like substance that fills the nucleus. Nucleoplasm plays a crucial role in maintaining the structural integrity of the nucleus and facilitating several essential functions within the cell nucleus. The Nuclear components such as the chromatin threads and the nucleolus remain suspended in the nucleoplasm.

The nucleoplasm has a complex chemical composition. It is composed of mainly the nucleoproteins but it also contains other inorganic and organic substances, viz., nucleic acids, proteins, enzymes and minerals.

1)Nucleic acids : The most common nucleic acids of the nucleoplasm are the DNA and RNA. Both may occur in the macromolecular state or in the form of their monomer nucleotides.

2)Proteins: The nucleoplasm contains many types of complex proteins. The nucleoproteins be categorized into following two types:

(i) Basic proteins. The proteins which take basic stain are known as the basic proteins. The most important basic proteins of the nucleus are **nucleoprotamines** and the **nucleohistones.**

(ii) Non-histone or Acidic. proteins. The acidic proteins either occur in the nucleoplasm or in the chromatin. The most abundant acidic proteins of the euchromatin (a type of chromatin) are the **phosphoproteins.**

3)Enzymes : The nucleoplasm contains many enzymes which are necessary for the synthesis of the DNA and RNA. Most of the nuclear enzymes are composed of non-histone (acidic) proteins. The most important nuclear enzymes are the DNA poly-merase, RNA polymerase, NAD synthetase, nucleoside triphosphatase, adenosine diaminase etc.

4)Minerals : The nucleoplasm also contains several inorganic compounds such as phosphorus, potassium, sodium, calcium and magnesium. The chromatin comparatively contains large amount of these minerals than the nucleoplasm.

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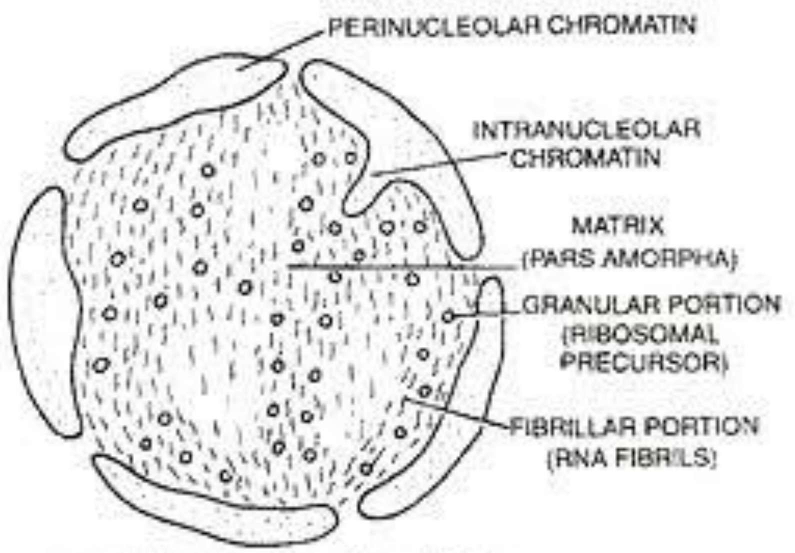
Nucleolus :

Nucleolus (first described by F. Fontana) is a non-membrane bound dynamic body which disappears in the late prophase and reappears in the telophase stage of cell division. Each nucleolus is produced by a Nucleolus-Organizing Region (NOR) of a chromosome which is termed as nucleolus-organizing chromosome. All eukaryotic cells contain at least one such chromosome. It is a site of transcription of ribosomal RNA and assembly of ribosome. rRNA genes present in the NOR of chromosome is responsible for synthesizing a large nascent pre-rRNA that is 45S in mammals and the processing (cleavage and base modification) of this RNA yield mature ribosomal RNA. The concomitant assembly of these RNAs with incoming ribosomal proteins generates small and large ribosomal subunits that then pass into the cytoplasm.

Nucleolus structure : It consists of three major regions.

Fibrillar centers: Containing rRNA genes in the form of partly condensed chromatin.
Fibrillar component: Surrounds the fibrillar centers, which contains RNA molecules in the process of transcription.
Granular regions: Outermost regions having mature ribosomal precursor particles.



Detailed structure of nucleolus.

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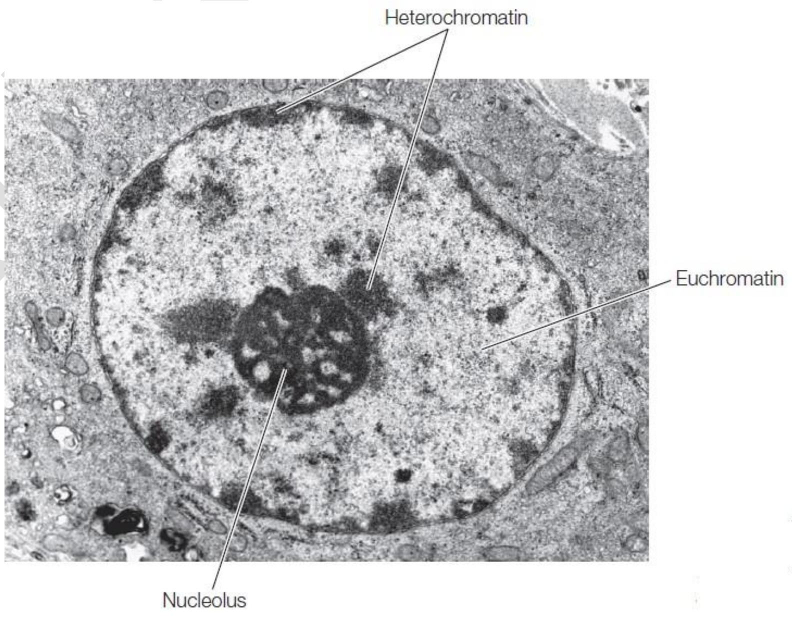
Chromatins :

The nucleoplasm contains many thread like, coiled and much elongated structures which readily take the basic stains such as the basic fuschin. These thread-like structures are known as chromatin substance or chromatin fibres. Chromatin becomes highly condensed during mitosis to form the compact metaphase chromosomes that are distributed to daughter nuclei. During interphase, most of the chromatin decondenses and is distributed throughout the nucleus. Although interphase chromatin appears to be uniformly distributed, the chromosomes actually occupy distinct regions of the nucleus and are organized such that the transcriptional activity of a gene is correlated with its position.

Most of the chromatin in interphase cells is decondensed and transcriptionally active called as **euchromatin** . The are lightly stained and are visualised as diffused region of the chromatin. The euchromatin contains comparatively large amount of DNA but some of the chromatin is highly condensed and not transcribed called as **heterochromatins**. They are darkly stained and are the condensed region of the chromatin. Heterochromatin includes DNA sequences that are generally not transcribed, such as the highly repetitive sequences present at centromeres and telomeres. Transcriptionally inactive heterochromatin is frequently associated with the nuclear envelope or periphery of the nucleolus, whereas transcriptionally active chromatin is preferentially localized to the interior of the nucleus or adjacent to nuclear pore complexes.



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Difference between Euchromatin and Heterchromatin :

Characteristic	Euchromatin	Heterochromatin
Structure	Less densely packed, diffuse	Highly condensed, densely packed
Gene Activity	Transcriptionally active	Transcriptionally silent or less active
Replication Timing	Replicates during early S-phase	Replicates during late S-phase
Location in Nucleus	More central, dispersed in the nucleus	Near the nuclear envelope or in specific regions (pericentromeric and telomeric)
Function	Contains actively transcribed genes	Contains silenced or inactive genes

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Chromatin packaging (Nucleosome)

DNA packaging is a crucial process in biology that involves the organization and compaction of long DNA molecules into a compact, space-efficient structure within the cell nucleus. Packaging is essential because the DNA in eukaryotic cells is remarkably long, with the human genome, for example, consisting of approximately 3 billion base pairs of DNA. Efficient packaging ensures that genetic material is protected, accessible, and properly regulated.

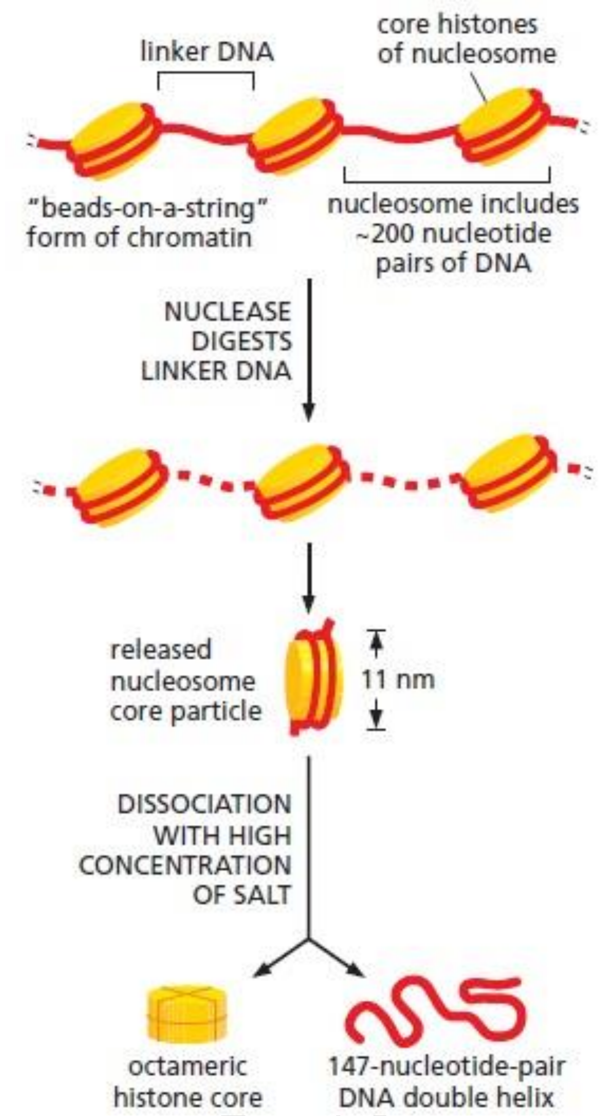
The **nucleosome model** is a fundamental concept in molecular biology that explains how genetic material is packaged and organized within the cell nucleus. It was first proposed by Roger Kornberg in the late 1970s and has since become a cornerstone of our understanding of chromatin structure and gene regulation. The nucleosome model describes how DNA is compacted and protected by histone proteins, allowing for the efficient storage, access, and regulation of genetic information.

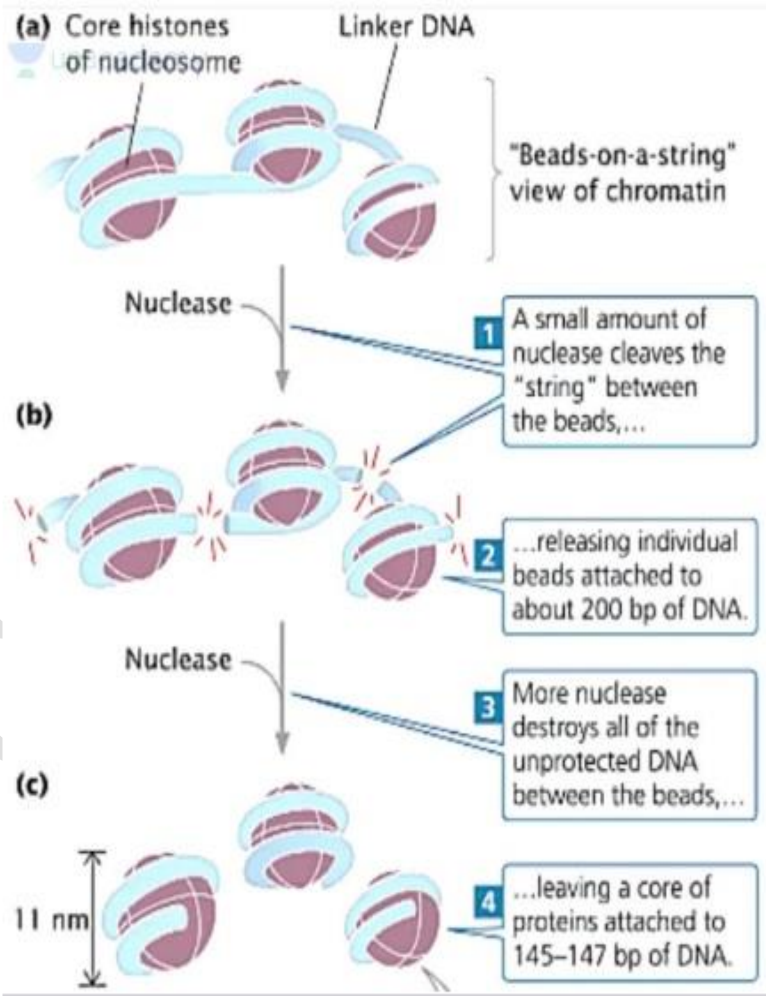
The proteins that bind to the DNA to form eukaryotic chromosomes are traditionally divided into two classes: the **histones** and the ***non-histone chromosomal proteins***, each contributing about the same mass to a chromosome as the DNA. The complex of both classes of protein with the nuclear DNA of eukaryotic cells is known as chromatin.

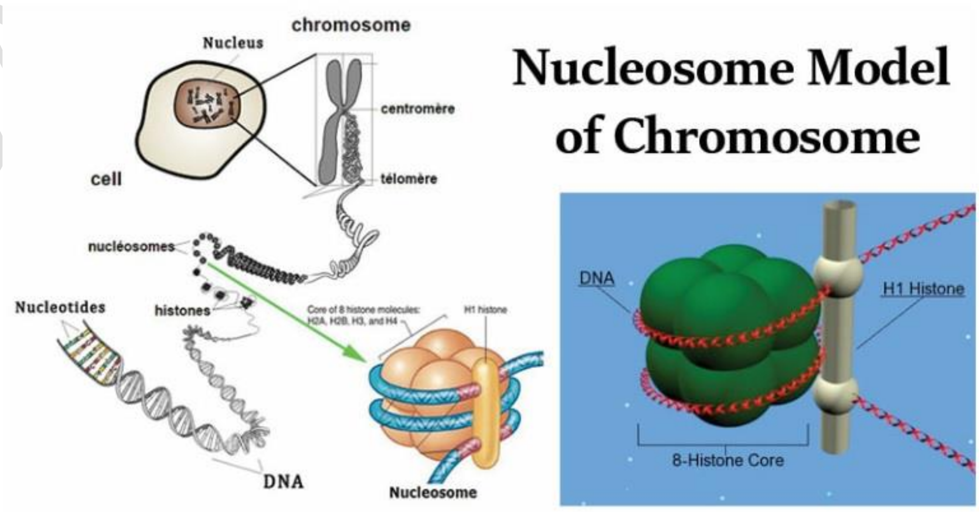
When interphase nuclei are broken open very gently and their contents examined under the electron microscope, most of the chromatin appears to be in the form of a fiber with a diameter of about 30 nm. If this chromatin is subjected to treatments that cause it to unfold partially, it can be seen under the electron microscope as a series of “beads on a string”. The string is DNA, and each bead is a “nucleosome core particle” that consists of DNA wound around a histone core.

Each individual nucleosome core particle consists of a complex of **eight histone proteins**—two molecules each of histones **H2A, H2B, H3, and H4**—and double stranded DNA that is 147 nucleotide pairs long. The ***histone octamer*** forms a protein core around which the double-stranded DNA is wound. **H1 histone** is not part of the core particle but crucial for nucleosome structure. H1 binds to DNA where it joins and leaves the octamer. The region of **linker DNA** that separates each nucleosome core particle from the next can vary in length from a few nucleotide pairs up to about 80.

On average, therefore, **nucleosomes repeat at intervals of about 200 nucleotide pairs**. For example, a diploid human cell with 6.4×10^9 nucleotide pairs contains approximately 30 million nucleosomes. The formation of nucleosomes converts a DNA molecule into a chromatin thread about one-third of its initial length.







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Function of the nucleus :

The nucleus is a membrane-bound organelle found in eukaryotic cells, and it serves as a central control center with a variety of crucial functions. Here's a broad overview of the functions of the nucleus:

1. **Storage of Genetic Material:** One of the most fundamental functions of the nucleus is to store genetic information in the form of DNA (deoxyribonucleic acid). DNA carries the instructions required for the synthesis of proteins and the regulation of cellular processes.
2. **DNA Replication:** The nucleus is the site where DNA replication occurs during the cell cycle. This process ensures that each daughter cell, produced during cell division, receives an identical copy of the genetic material.
3. **Transcription:** Within the nucleus, the process of transcription takes place, where a specific segment of DNA is used as a template to synthesize messenger RNA (mRNA). mRNA carries the genetic code from the nucleus to the cytoplasm, where it is translated into proteins.
4. **Ribosome Biogenesis:** The nucleolus, a specialized region within the nucleus, is responsible for the assembly of ribosomes. Ribosomes are the cellular machinery responsible for protein synthesis, and they are composed of ribosomal RNA (rRNA) and protein subunits.
5. **mRNA Processing:** After transcription, mRNA undergoes various modifications within the nucleus, such as capping, splicing, and polyadenylation. These modifications prepare the mRNA for export to the cytoplasm and ensure its stability and functionality.
6. **DNA Repair:** The nucleus houses the machinery required for DNA repair. Cells continuously monitor DNA integrity, and when damage occurs, repair mechanisms are activated to correct mutations and maintain genomic stability.
7. **Cell Cycle Regulation:** The nucleus contains proteins and checkpoints that regulate the cell cycle, ensuring that cell division occurs in an orderly and controlled manner. This regulation is crucial for growth, development, and tissue repair.

In summary, the nucleus is a multifunctional organelle responsible for storing, processing, and regulating genetic information, as well as controlling key cellular processes. Its functions are essential for the survival, growth, and specialization of eukaryotic cells.

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