Lecture Outline: The Cell Cycle and Cell Division

I. **Overview of the Cell Cycle**
   A. **Definition and Duration**
      1. Begins when a cell is created and ends when it splits into two new cells, representing one generation of cells.
      2. Duration varies depending on species and conditions; can be hours or days.
   B. **Importance of Cell Division**
      1. **Reproduction**
         a. Primary method for unicellular organisms to reproduce, where the parent cell ceases to exist by dividing into two offspring cells.
      2. **Growth and Development**
         a. In multicellular organisms, growth involves increasing the number of cells through division.
         b. Development involves cells taking on specific roles and differentiating into various types (e.g., nerve, muscle cells).
      3. **Tissue Renewal**
         a. Applies only to multicellular organisms, involving the replacement of damaged, killed, or intentionally died cells.
         b. Examples include the continuous replacement of red blood cells (which lose their nucleus and cannot repair themselves) and skin cells.

II. **Genetic Material: Chromatin, Chromosomes, and DNA Functions**
   A. **Chromatin**
      1. A mixture of **proteins and DNA** that constitutes the genetic material.
      2. Appears as a diffuse "tangle" within the nucleus during most of the cell cycle, as individual structures are not visible.

3. Begins to **condense** and become tighter as the cell prepares to divide.
4. Needs to be **loose** and unwound for DNA's critical function of transcription.

B. **Chromosomes**

1. A highly **compact** and discrete structure formed from condensed chromatin.
2. Term is used when chromatin becomes visible as individual, separate structures.
3. By the time chromatin is condensed enough to be called a chromosome, **DNA replication has already occurred**.
4. A **replicated chromosome** consists of two genetically **identical sister chromatids** joined together at a central point called the **centromere**.
5. An **unreplicated chromosome** is a single piece of DNA, typically seen after sister chromatids separate.
6. Unreplicated chromosomes quickly unravel (decondense) in daughter cells to allow for gene transcription.

C. **DNA Functions**

1. **Replication**
   a. The process of copying DNA, ensuring that each new daughter cell receives a **full and complete complement of genetic material**.
   b. Occurs during the S phase of interphase, before chromatin condensation.
2. **Transcription**
   a. The process where DNA serves as a code for synthesizing proteins, essential for the cell's specific functions.
   b. Requires the DNA to be in a loose, unwound state to be accessible for gene reading.

III. **The Eukaryotic Cell Cycle**

A. **Major Subdivisions**

1. **Interphase**
   a. Represents the **majority of the cell cycle's duration**, a period of

growth and preparation for division.

b. Consists of three phases:
    1. **G1 Phase (First Gap)**: The primary period of a cell's life, where it performs its specialized functions. DNA is actively used for transcription.
    2. **S Phase (Synthesis)**: The crucial phase where **DNA replication occurs**, and the centrosome also duplicates. At this point, the cell is committed to dividing.
    3. **G2 Phase (Second Gap)**: A period of further growth and preparation for cell division, involving the transcription of genes necessary for mitosis. The cell now has two centrosomes and its nuclear envelope is intact.

2. **M Phase (Mitotic Phase)**
    a. The actual period of **cell division**, comprising two distinct processes: **Mitosis** and **Cytokinesis**.
    b. It is important to note that the M phase is not synonymous with mitosis alone.
        1. **Mitosis**: The division of the nucleus and its genetic contents.
            1. Occurs only in eukaryotic cells, which possess a true nucleus.
            2. Ensures that each resulting nucleus receives a complete and identical set of DNA.
            3. Subphases of Mitosis:
                1. **G2 of Interphase**: Pre-mitosis state, with replicated DNA and two centrosomes, nuclear envelope intact.
                2. **Prophase**: Microtubules begin forming the early mitotic spindle from separating centrosomes. Chromatin condenses into distinct chromosomes, but the nuclear envelope remains intact.
                3. **Prometaphase**: Chromosomes further condense, the **nuclear envelope disintegrates**. The mitotic spindle matures, and microtubules attach to

chromosomes at protein complexes called **kinetochores**. Non-kinetochore (polar) microtubules push poles apart.

4. **Metaphase**: The **replicated chromosomes align at the metaphase plate** (an imaginary equatorial plane), positioned halfway between the two poles. This alignment is facilitated by kinetochore microtubules and motor proteins.
5. **Anaphase**: The crucial stage where **sister chromatids separate** from each other and are now considered individual, unreplicated chromosomes, moving towards opposite poles of the cell.
6. **Telophase**: The unreplicated chromosomes arrive at the poles. New nuclear envelopes form around each set of chromosomes, resulting in two distinct nuclei within one elongated cell.

2. **Cytokinesis**: The division of the cytoplasm, which typically begins during telophase and overlaps with it.
   1. Involves the rough division of cytoplasmic components (organelles, etc.) between the two nascent daughter cells.
   2. **In Animal Cells**: A **cleavage furrow** forms, a contracting ring of actin microfilaments and motor proteins that pinches the cell into two separate, genetically identical daughter cells.
   3. **In Plant Cells**: Due to the rigid cell wall, a cleavage furrow cannot form. Instead, **vesicles containing cell wall material form at the metaphase plate**, fuse to create a **cell plate**, which then grows outward to form a new cell wall separating the two daughter cells.

IV. **Cell Division in Prokaryotes: Binary Fission**

A. Prokaryotic cells (e.g., bacteria) lack a nucleus and therefore **do not undergo mitosis**.

B. Their cell division process is called **binary fission**, meaning "splitting in two."

C. Prokaryotes typically have a single, circular chromosome, which must replicate before binary fission occurs to ensure each daughter cell receives a full DNA set.

D. Binary fission achieves the same outcome as mitosis and cytokinesis combined in eukaryotes.

V. **Regulation of the Cell Cycle**

A. **Evidence for Chemical Signals**

1. Cell fusion experiments demonstrated that chemical signals control the cell cycle; for instance, fusing a G1 cell with an S-phase cell causes the G1 nucleus to immediately begin DNA replication.

B. **Checkpoints**

1. Not physical structures, but rather **sets of conditions** that must be met for a cell to progress from one phase to the next.
2. The **G1 Checkpoint is critically important** as it represents the cell's "decision point" to either commit to dividing or continue its normal functions.
3. Cells that indefinitely remain in G1 (receiving a "red light" at the checkpoint) are considered to be in the **G0 phase** (e.g., mature neurons).

C. **Key Molecular Regulators**

1. **Cyclin**
   a. A protein whose concentration **builds up gradually** during the cell cycle, synthesized by the cell itself.
   b. Its concentration drops rapidly after mitosis is complete.
2. **CDK (Cyclin-Dependent Kinase)**
   a. An enzyme that is always present in the cell but is **only active when bound to Cyclin**.
   b. As a kinase, CDK phosphorylates (adds phosphate groups to) other molecules, often activating other enzymes, to promote progression through the cell cycle.

   c. High levels of Cyclin lead to maximum CDK activity, exemplified by MPF (Maturation-Promoting Factor), which triggers mitosis.

3. **Growth Factors (e.g., PDGF - Platelet-Derived Growth Factor)**
   a. Signal molecules that stimulate cell proliferation and tissue growth (increase in cell numbers).
   b. For example, fibroblasts will only divide if a growth factor like PDGF is present.

D. **External Signals and Inhibition**

1. **Anchorage Dependence**: Some cells, such as epithelial cells, require attachment to a surface (a mechanical signal) to receive permission to divide.
2. **Density-Dependent Inhibition**: Cells stop dividing when they become crowded and contact other cells, signaling that the available space has been filled.

E. **Cancer: Uncontrolled Cell Division**

1. Cancer is a **genetic disorder** characterized by the **loss of normal cell cycle control**, leading to uncontrolled cell division.
2. It arises from **defects in DNA or genes** that code for the proteins involved in regulating the cell cycle's signals.
3. These genetic defects can accumulate over time due to environmental factors (e.g., UV radiation) or accidental errors during DNA replication.
4. **Tumors** are localized masses of continuously dividing defective cells.
5. **Metastasis** occurs when cancerous cells break away from the primary tumor, travel through the bloodstream or lymphatic system, and establish new tumors in other parts of the body, making the cancer life-threatening. Early detection is crucial to prevent metastasis.