Phases of the Cell Cycle

The cell cycle is a series of stages that cells go through to grow and divide. It consists of four main phases: G1, S, G2, and M.

1. **G1 Phase (First Gap Phase)**:
    - **Cell Growth**: The cell increases in size and synthesizes various enzymes and nutrients needed for DNA replication and cell division.
    - **Preparation for S Phase**: The cell ensures it has the necessary energy and molecular components to proceed to the next phase.
    - **G1 Checkpoint**: The cell evaluates whether conditions are favorable for DNA replication. If the environment is not suitable or DNA is damaged, the cell can enter a resting state (G0 phase) or undergo apoptosis.
2. **S Phase (Synthesis Phase)**:
    - **DNA Replication**: The cell synthesizes a complete copy of its DNA. Each chromosome is replicated to form two sister chromatids held together by a centromere.
    - **Centrosome Duplication**: The centrosome, which helps organize the microtubules during mitosis, also duplicates.
3. **G2 Phase (Second Gap Phase)**:
    - **Further Growth**: The cell continues to grow and produce proteins necessary for mitosis.
    - **Preparation for Mitosis**: The cell ensures all DNA is accurately replicated and repairs any DNA damage.
    - **G2 Checkpoint**: The cell verifies that DNA replication is complete and the DNA is undamaged. If issues are detected, the cell cycle is halted until repairs are made.
4. **M Phase (Mitosis)**:
    - **Mitosis**: The division of the cell's nucleus into two genetically identical daughter nuclei.
    - **Cytokinesis**: The division of the cell's cytoplasm, resulting in two separate daughter cells.

Mechanisms and Regulation of Mitosis and Meiosis

Mitosis:

- **Purpose**: To produce two genetically identical daughter cells for growth, repair, and asexual reproduction.
- **Phases**:
    1. **Prophase**:
        - Chromosomes condense and become visible.
        - The nuclear envelope breaks down.
        - The mitotic spindle forms and centrosomes move to opposite poles.
    2. **Prometaphase**:
        - The spindle fibers attach to kinetochores on the centromeres of the chromosomes.

3. **Metaphase**:
    - Chromosomes align at the metaphase plate (the cell's equatorial plane).
4. **Anaphase**:
    - Sister chromatids separate and move to opposite poles of the cell.
5. **Telophase**:
    - Chromosomes decondense.
    - The nuclear envelope re-forms around each set of chromosomes, creating two nuclei.
6. **Cytokinesis**:
    - The cytoplasm divides, resulting in two separate daughter cells.

Meiosis:

- **Purpose**: To produce haploid gametes (sperm and egg cells) for sexual reproduction, reducing the chromosome number by half and introducing genetic diversity.
- **Phases**:
    - **Meiosis I**:
        1. **Prophase I**:
            - Homologous chromosomes pair up (synapsis) and exchange genetic material (crossing over).
            - The nuclear envelope breaks down, and the spindle apparatus forms.
        2. **Metaphase I**:
            - Homologous pairs align at the metaphase plate.
        3. **Anaphase I**:
            - Homologous chromosomes (each with two sister chromatids) are pulled to opposite poles.
        4. **Telophase I and Cytokinesis**:
            - Chromosomes arrive at the poles, and the cell divides, resulting in two haploid daughter cells.
    - **Meiosis II** (similar to mitosis but starting with haploid cells):
        1. **Prophase II**:
            - Chromosomes condense, and the nuclear envelope breaks down.
            - A new spindle apparatus forms.
        2. **Metaphase II**:
            - Chromosomes align at the metaphase plate.
        3. **Anaphase II**:
            - Sister chromatids separate and move to opposite poles.
        4. **Telophase II and Cytokinesis**:
            - Chromosomes arrive at the poles, and the nuclear envelope re-forms.
            - The cells divide, resulting in four genetically distinct haploid gametes.

Checkpoints and Cell Cycle Control

Checkpoints:

- **G1 Checkpoint (Restriction Point)**:
  - Assesses the cell size, nutrients, growth factors, and DNA integrity.
  - If conditions are not favorable, the cell may enter the G0 phase or initiate apoptosis.
- **G2 Checkpoint**:
  - Ensures DNA replication is complete and DNA is undamaged.
  - Prevents entry into mitosis if DNA is not fully replicated or is damaged.
- **M Checkpoint (Spindle Assembly Checkpoint)**:
  - Verifies that all chromosomes are correctly attached to the spindle apparatus before anaphase.
  - Prevents chromosome mis segregation and aneuploidy.

Regulation of the Cell Cycle:

- **Cyclins and Cyclin-Dependent Kinases (CDKs)**:
  - **Cyclins**: Regulatory proteins whose levels fluctuate throughout the cell cycle.
  - **CDKs**: Enzymes that, when activated by binding to cyclins, phosphorylate target proteins to drive cell cycle progression.
  - Different cyclin-CDK complexes regulate specific phases of the cell cycle.
- **Tumor Suppressors**:
  - **p53**: A protein that activates DNA repair proteins, induces cell cycle arrest at the G1 checkpoint, or triggers apoptosis if DNA damage is irreparable.
  - **RB (Retinoblastoma Protein)**: Inhibits cell cycle progression from G1 to S phase; its activity is regulated by phosphorylation.
- **Proto-Oncogenes and Oncogenes**:
  - **Proto-Oncogenes**: Normal genes that promote cell division and survival.
  - **Oncogenes**: Mutated proto-oncogenes that drive uncontrolled cell proliferation, leading to cancer.
- **Apoptosis (Programmed Cell Death)**:
  - An orderly process by which cells undergo self-destruction in response to DNA damage or other signals.
  - Ensures damaged or unnecessary cells are eliminated without causing inflammation.

Understanding these aspects of the cell cycle and division, including the regulation mechanisms, is crucial for comprehending how cells grow, replicate, and maintain genomic integrity.