Mitosis is part of the cell cycle in which an existing cell (the parent cell) divides into two (the daughter cells). Unlike meiosis, mitosis does not result in a change of chromosome numbers and the daughter cells are identical to the parent cell. Although mitosis is part of a continuous cell cycle, it is divided into stages (below). The example below illustrates the cell cycle in a plant cell. Note that cytokinesis in plant cells involves construction of a cell plate in the middle of the cell where Golgi vesicles release components for the construction of a new cell wall. In animal cells, cytokinesis involves the formation of a constriction that divides the cell into two. It is usually well underway by the end of telophase and does not involve the formation of a cell plate.

**The Cell Cycle and Stages of Mitosis**

**A. Interphase**
- DNA is replicated
- Cell enters mitosis
- The centrosome, which later forms the spindle, is also replicated. Plant cell centrosomes lack centrioles. In animal cells, centrioles are associated with the centrosomes.

**B. Late Prophase**
- DNA continues condensing into chromosomes and the nuclear membrane begins to disintegrate
- Homologous pair of replicated chromosomes
- Chromosomes continue to condense. Each one appears as two chromatids held together at the centromere. Spindle begins to form.

**C. Metaphase**
- spindle fibres attach to the centromeres of the chromosomes and some span the cell.
- The mitotic spindle is made up of microtubules and proteins. It organises the chromosomes on the equator of the cell. Some spindle fibres attach to the centromeres of the chromosomes and some span the cell.

**D. Late Anaphase**
- The centromeres divide and spindle fibres attached to chromatids shorten, pulling the chromatids apart.
- Other spindle fibres lengthen, pushing the poles apart and causing the cell to elongate.

**E. Telophase**
- Two new nuclei form. The cell plate forms across the midline of the parent cell. This is where the new cell wall will form.

**F. Cytokinesis**
- Cytokinesis (division of the cytoplasm) is complete. The two daughter cells are now separate cells in their own right.

**The Cell Cycle Overview**

- **S Phase:** Chromosome replication (DNA synthesis)
- **G1 Phase:** Cell growth and development
- **G2 Phase:** The chromosomes begin condensing
- **Mitosis:** Nuclear division
- **Cytokinesis:** The cytoplasm divides, and the two cells separate. Cytokinesis is distinct from nuclear division.

*Animal cell cytokinesis (above) begins shortly after the sister chromatids have separated in anaphase of mitosis. A contractile ring of microtubular elements assembles in the middle of the cell, next to the plasma membrane, constricting it to form a cleavage furrow. In an energy-using process, the cleavage furrow moves inwards, forming a region of abscission where the two cells will separate. In the photograph above, an arrow points to a centrosome, which is still visible near the nucleus.*

**Related activities:** Mitosis vs Meiosis

**Weblinks:** Mitosis in an Animal Cell
**Binary Fission**

**Binary fission** is a form of asexual reproduction carried out by most prokaryotes (bacteria and cyanobacteria), in some eukaryotic organelles, such as mitochondria and chloroplasts, and by some unicellular eukaryotes (although the process is somewhat different in eukaryotic cells). In this process, the parent body divides into two, fairly equal, parts to produce two identical cells. The time required for a bacterial cell to divide, or for a population of bacterial cells to double, is called the generation time. Generation times may be quite short (20 minutes) while some species may have a generation time of several days.

Most bacteria reproduce asexually by binary fission (left). The cell's DNA is replicated and each copy attaches to a different part of the plasma membrane. When the cell begins to pull apart, the replicate and original chromosomes are separated. Binary fission in bacteria does not involve mitosis or cytokinesis.

1. What is binary fission?

2. Explain why the formation of the cross wall is important in binary fission:

3. Explain the term generation time:

4. A species of bacteria reproduces every 20 minutes. Complete the table (left) by calculating the number of bacteria present at 20 minute intervals.

5. State how many bacteria were present after:
   (a) 1 hour: 
   (b) 3 hours: 
   (c) 6 hours: 

---

<table>
<thead>
<tr>
<th>Generation time (minutes)</th>
<th>Population size</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
</tr>
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<td>40</td>
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<tr>
<td>340</td>
<td></td>
</tr>
<tr>
<td>360</td>
<td></td>
</tr>
</tbody>
</table>
Mitotic cell division has several purposes (below left). In multicellular organisms, mitosis repairs damaged cells and tissues, and produces the growth in an organism that allows it to reach its adult size. In unicellular organisms, and some small multicellular organisms, cell division allows organisms to reproduce asexually (as in the budding yeast cell cycle below).

### The Functions of Mitosis

1. **Growth**
   In plants, cell division occurs in regions of meristematic tissue. In the plant root tip (right), the cells in the root apical meristem are dividing by mitosis to produce new cells. This elongates the root, resulting in plant growth.

2. **Repair**
   Some animals, such as this skink (left), detach their limbs as a defence mechanism in a process called autotomy. The limbs can be regenerated via the mitotic process, although the tissue composition of the new limb differs slightly from that of the original.

3. **Reproduction**
   Mitotic division enables some animals to reproduce asexually. The cells of this Hydra (left) undergo mitosis, forming a 'bud' on the side of the parent organism. Eventually the bud, which is genetically identical to its parent, detaches to continue the life cycle.

---

1. The photographs below were taken at various stages through mitosis in a plant cell. They are not in any particular order. Study the diagram on the previous page and determine the stage represented in each photograph (e.g. anaphase).

   ![Photographs of cell division stages](image)

   (a) ___________  (b) ___________  (c) ___________  (d) ___________  (e) ___________

2. State two important changes that chromosomes must undergo before cell division can take place: ____________________________

3. Briefly summarise the stages of the cell cycle by describing what is happening at the points (A-F) in the diagram on the previous page:

   A. ____________________________
   B. ____________________________
   C. ____________________________
   D. ____________________________
   E. ____________________________
   F. ____________________________
Regulation of the Cell Cycle

The events of mitosis are virtually the same for all eukaryotes. However, aspects of the cell cycle can vary enormously between species and even between cells of the same organism. For example, the length of the cell cycle varies between cells such as intestinal and liver cells. Intestinal cells divide around twice a day, while cells in the liver divide once a year. However, if these tissues are damaged, cell division increases rapidly until the damage is repaired. Variation in the length of the cell cycle can be explained by the existence of a regulatory mechanism that slows down or speeds up the cell cycle in response to changing conditions.

A substance called an M-phase promoting factor (MPF) controls cell regulation. MPF is made up of two regulatory molecules, cyclins and cyclin-dependent kinases (CDKs).

Cyclins are proteins that control the progression of cells through the cell cycle by activating CDKs (which are enzymes).

CDKs phosphorylate other proteins to signal a cell is ready to proceed to the next stage in the cell cycle. Without cyclin, CDK has little kinase activity; only the cyclin-CDK complex is active. CDK is constantly present in the cell, cyclin is not.

Checkpoints During the Cell cycle

There are three checkpoints during the cell cycle. A checkpoint is a critical regulatory point in the cell cycle. At each checkpoint, a set of conditions determines whether or not the cell will continue into the next phase. For example, cell size is important in regulating whether or not the cell can pass through the G₁ checkpoint.

**G₁ checkpoint**

Pass this checkpoint if:
- Cell size is large enough.
- Sufficient nutrients are available.
- Signals from other cells have been received.

**G₂ Checkpoint:**

Pass this checkpoint if:
- Cell size is large enough.
- Replication of chromosomes has been successfully completed.

**Metaphase checkpoint**

Pass this checkpoint if:
- All chromosomes are attached to the mitotic spindle.

1. What would happen if the cell cycle was not regulated?

   

2. (a) Suggest why the cell cycle is shorter in epithelial cells (such as intestinal cells) than in liver cells:

   

   (b) Describe another situation in which the cell cycle shortens to allow for a temporary rapid rate of cell division:
**Stages in Meiosis**

Meiosis is a special type of cell division concerned with producing sex cells (gametes) for the purpose of sexual reproduction. It involves a single chromosomal duplication followed by two successive nuclear divisions, and results in a halving of the diploid chromosome number. Meiosis occurs in the sex organs of plants and animals. If genetic mistakes (gene and chromosome mutations) occur here, they will be passed on to the offspring (they will be inherited).

**Meiosis I**
(Reduction division)
The first division separates the homologous chromosomes into two intermediate cells.

1. Describe the behaviour of the chromosomes in the first division of meiosis:
   
2. Describe the behaviour of the chromosomes in the second division of meiosis:

Meiosis is preceded by DNA replication, during which each of the chromosomes replicates. For each chromosome, there are now two genetically identical sister chromatids (as yet unseparated). It is at this stage that mutations may occur. The chromosome are not visibly as discrete structures at this point. We have drawn them this way to show the maternal and paternal chromosomes.

Chromosomes condense. The homologs, each consisting of two sister chromatids, pair up to form bivalents. At this stage the arms of the chromatids can become entangled, and segments of chromosome can be exchanged in a process called crossing over. The meiotic spindle forms.

The bivalents line up at the 'equator' (the metaphase plate) of the cell in a way that is random. This results in independent assortment of maternal and paternal chromosomes.

**Meiosis II**
The second division is merely a mitotic one in nature, where the chromatids are pulled apart, but the number of chromosomes remains the same. This allows large numbers of gametes to be produced.

Spindle apparatus forms. Chromosomes migrate towards the metaphase plate.

Chromosomes line up on the metaphase plate.

Sister chromatids (now individual chromosomes) separate.

Related activities: Mitosis vs Meiosis

Weblinks: Meiosis, Independent Assortment of Alleles
Mitosis vs Meiosis

Cell division is fundamental to all life, as cells arise only by the division of existing cells. All types of cell division begin with replication of the cell's DNA. In eukaryotes, this is followed by division of the nucleus. There are two forms of nuclear division: mitosis and meiosis, and they have quite different purposes and outcomes. Mitosis is the simpler of the two and produces two identical daughter cells from each parent cell. Mitosis is responsible for growth and repair processes in multicellular organisms and reproduction in single-celled and asexual eukaryotes. Meiosis involves a reduction division in which haploid gametes are produced for the purposes of sexual reproduction. Fusion of haploid gametes in fertilisation restores the diploid cell number in the zygote. These two fundamentally different types of cell division are compared below.

**Mitosis**

1. Homologous chromosomes do not pair up at the equatorial plate.
2. Homologous chromosomes pair up at the equatorial plate.

**Meiosis**

1. Genetic material can be exchanged between chromosomes in meiosis I.
2. Cell division.

1. Explain how mitosis conserves chromosome number while meiosis reduces the number from diploid to haploid:

   

2. Describe a fundamental difference between the first and second divisions of meiosis:

   

3. How does meiosis introduce genetic variability into gametes and offspring (following gamete fusion in fertilisation)?

   

Related activities: Mitosis and the Cell Cycle, Meiosis
Enzyme Control of DNA Replication

The sequence of enzyme controlled events in DNA replication is shown below (1-5). Although shown as separate, many of the enzymes are found clustered together as enzyme complexes. These enzymes are also able to 'proof-read' the new DNA strand as it is made and correct mistakes. The polymerase enzyme can only work in one direction, so that one new strand is constructed as a continuous length (the leading strand) while the other new strand is made in short segments to be later joined together (the lagging strand). NOTE that the nucleotides are present as deoxyribonucleotide triphosphates. When hydrolysed, these provide the energy for incorporating the nucleotide into the strand.

1. What is the purpose of DNA replication? ___________________________________________________________________________

2. Summarise the steps involved in DNA replication (previous activity):
   (a) Step 1: __________________________________________________________________________________________
   (b) Step 2: __________________________________________________________________________________________
   (c) Step 3: __________________________________________________________________________________________

3. Explain the role of the following enzymes in DNA replication:
   (a) Helicase: ________________________________________________________________________________________
   (b) DNA polymerase I: ________________________________________________________________________________
   (c) DNA polymerase III: ______________________________________________________________________________
   (d) Ligase: _________________________________________________________________________________________

4. Determine the time it would take for a bacteria to replicate its DNA (see note in diagram above): ____________

Related activities: DNA Replication
Web links: DNA Replication (Answer)
Protein Synthesis Summary

The diagram above shows an overview of the process of protein synthesis. It is a combination of the diagrams from the previous two pages. Each of the major steps in the process are numbered, while structures are labelled with letters.

1. Briefly describe each of the numbered processes in the diagram above:
   
   (a) Process 1:  

   (b) Process 2:  

   (c) Process 3:  

   (d) Process 4:  

   (e) Process 5:  

   (f) Process 6:  

   (g) Process 7:  

   (h) Process 8:  

2. Identify each of the structures marked with a letter and write their names below in the spaces provided:

   (a) Structure A:  

   (b) Structure B:  

   (c) Structure C:  

   (d) Structure D:  

   (e) Structure E:  

   (f) Structure F:  

   (g) Structure G:  

   (h) Structure H:  

   (i) Structure I:  

   (j) Structure J:  

3. Describe two factors that would determine whether or not a particular protein is produced in the cell:

   (a)  

   (b)  

Related activities: Transcription in Eukaryotes, Translation

Periodicals: 
Gene structure and
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>allele</td>
<td>Single stranded nucleic acid that consists of nucleotides that contain ribose sugar.</td>
</tr>
<tr>
<td>anticodon</td>
<td>Organic macromolecules composed of linear chains of amino acids joined together by peptide bonds and then organized, e.g. through folding, into a functional structure.</td>
</tr>
<tr>
<td>autosome</td>
<td>The process by which genetic information is used to produce a functional gene product.</td>
</tr>
<tr>
<td>base-pairing rule</td>
<td>A set of rules by which information encoded in DNA or mRNA is translated into proteins.</td>
</tr>
<tr>
<td>chromatid</td>
<td>The rule governing the pairing of complementary bases in DNA.</td>
</tr>
<tr>
<td>chromosome</td>
<td>The region of a transfer RNA with a sequence of three bases that are complementary to a codon in the messenger RNA.</td>
</tr>
<tr>
<td>coding strand</td>
<td>DNA regions within a gene that are not translated into protein.</td>
</tr>
<tr>
<td>diploid</td>
<td>A two-ringed compound comprising a pyrimidine (6 sides) fused with a imidazole (5 sides) ring. Adenine and guanine are both purine compounds and act as bases in DNA.</td>
</tr>
<tr>
<td>DNA</td>
<td>The number and appearance of chromosomes in the nucleus of a eukaryotic cell.</td>
</tr>
<tr>
<td>exons</td>
<td>The process of creating an equivalent RNA copy of a sequence of DNA.</td>
</tr>
<tr>
<td>gene expression</td>
<td>Single piece of DNA that contains many genes and associated regulatory elements and proteins. Found within the nucleus in eukaryotes and as a singular circular piece in prokaryotes.</td>
</tr>
<tr>
<td>genetic code</td>
<td>Form of intermolecular bonding between hydrogen and an electronegative atom such as oxygen.</td>
</tr>
<tr>
<td>hydrogen bonding</td>
<td>The sequence of DNA that is read during the synthesis of mRNA.</td>
</tr>
<tr>
<td>introns</td>
<td>Universally found macromolecules composed of chains of nucleotides. These molecules carry genetic information within cells.</td>
</tr>
<tr>
<td>karyotype</td>
<td>The DNA strand with the same base sequence as the RNA transcript produced (although with thymine replaced by uracil in mRNA).</td>
</tr>
<tr>
<td>nucleic acids</td>
<td>A non-sex chromosome.</td>
</tr>
<tr>
<td>nucleotides</td>
<td>Macromolecule consisting of many millions of units containing a phosphate group, sugar and a base (A, T, C or G). Stores the genetic information of the cell.</td>
</tr>
<tr>
<td>protein</td>
<td>The structural units of nucleic acids, DNA and RNA.</td>
</tr>
<tr>
<td>purine</td>
<td>A single ringed compound with ( N ) atoms at positions 1 and 3. The pyrimidines cytosine, and thymine act as bases in DNA, with uracil replacing thymine in RNA.</td>
</tr>
<tr>
<td>pyrimidine</td>
<td>Having two homologous copies of each chromosome (2N), usually one from the mother and one from the father.</td>
</tr>
<tr>
<td>RNA (mRNA, tRNA, rRNA)</td>
<td>Nucleic acid sequences that are represented in the mature form of an RNA molecule.</td>
</tr>
<tr>
<td>sex chromosome</td>
<td>The chromosome that carries the gene for determination of sex in individual organisms.</td>
</tr>
<tr>
<td>template strand</td>
<td>The stage of gene expression in which mRNA is decoded to produce a polypeptide.</td>
</tr>
<tr>
<td>transcription</td>
<td>One of a pair of duplicated chromosomes produced prior to cell division, joined at the centromere.</td>
</tr>
<tr>
<td>translation</td>
<td>One of a number of alternative versions of a gene that can occupy a given genetic locus on a chromosome.</td>
</tr>
</tbody>
</table>