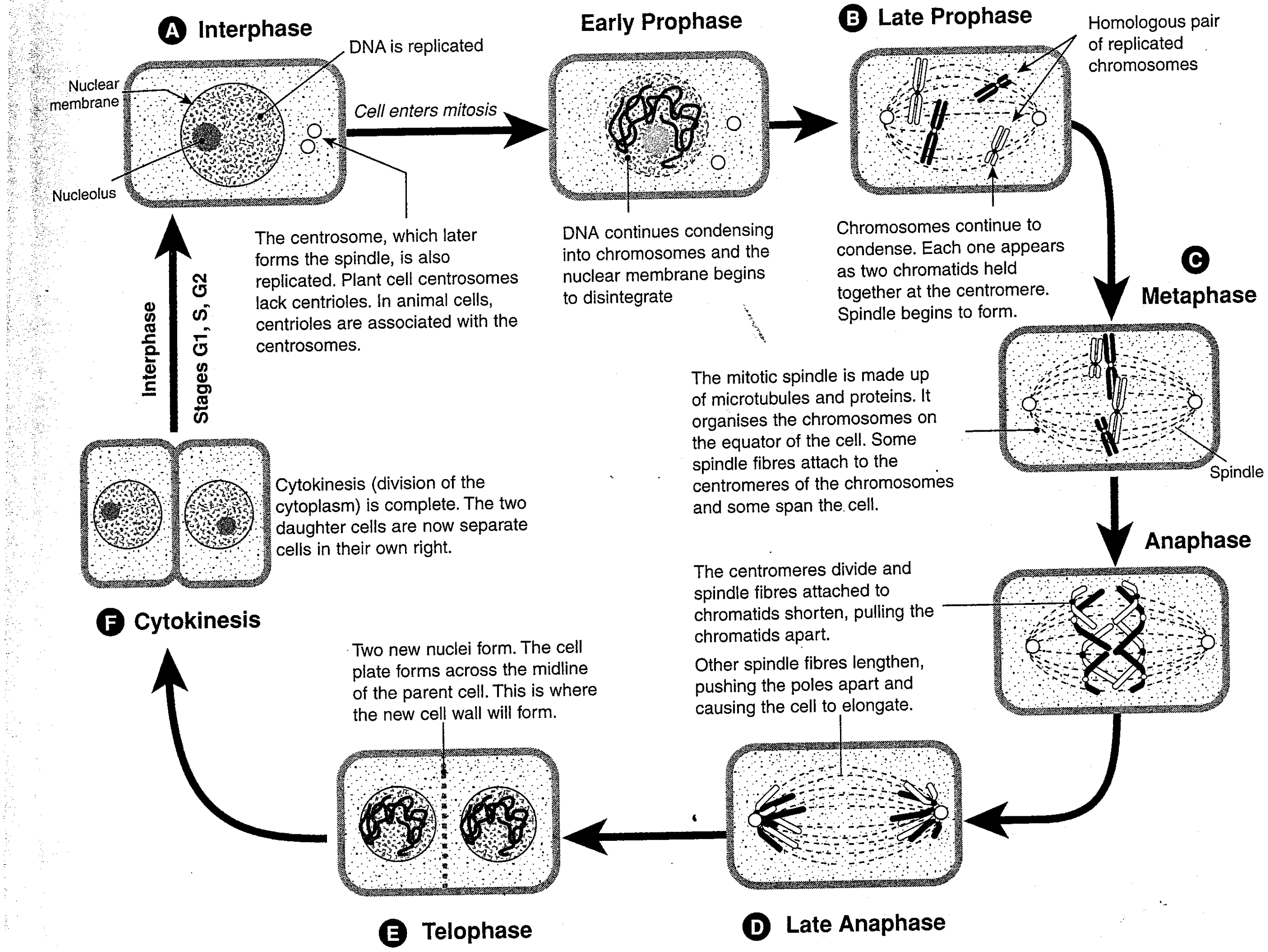
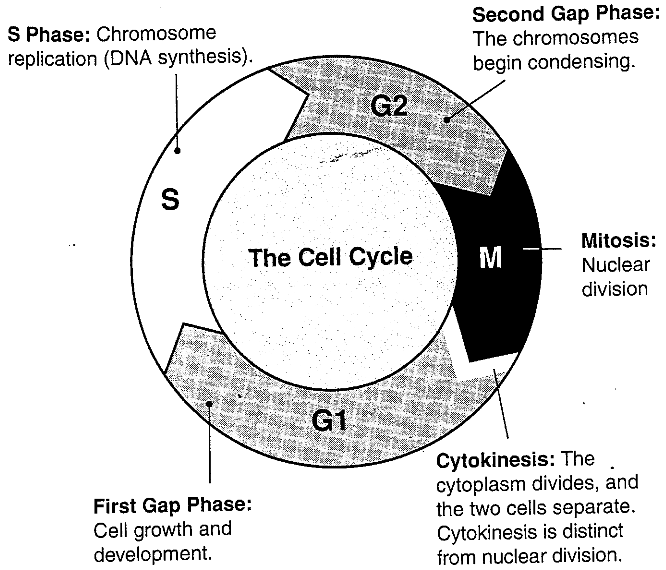
Mitosis and the Cell Cycle

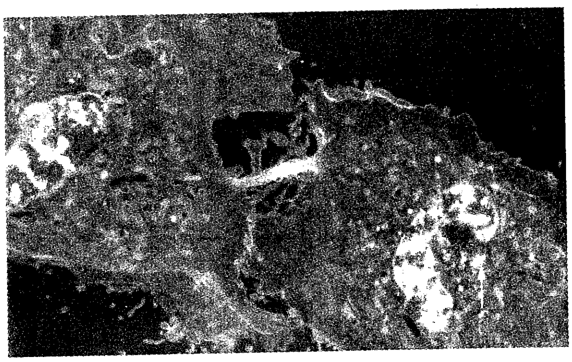
Mitosis is part of the **cell cycle** in which an existing cell (the parent cell) divides into two (the daughter cells). Unlike meiosis, mitosis does not result in a change of chromosome numbers and the daughter cells are identical to the parent cell. Although mitosis is part of a continuous cell cycle, 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 in 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



The Cell Cycle Overview





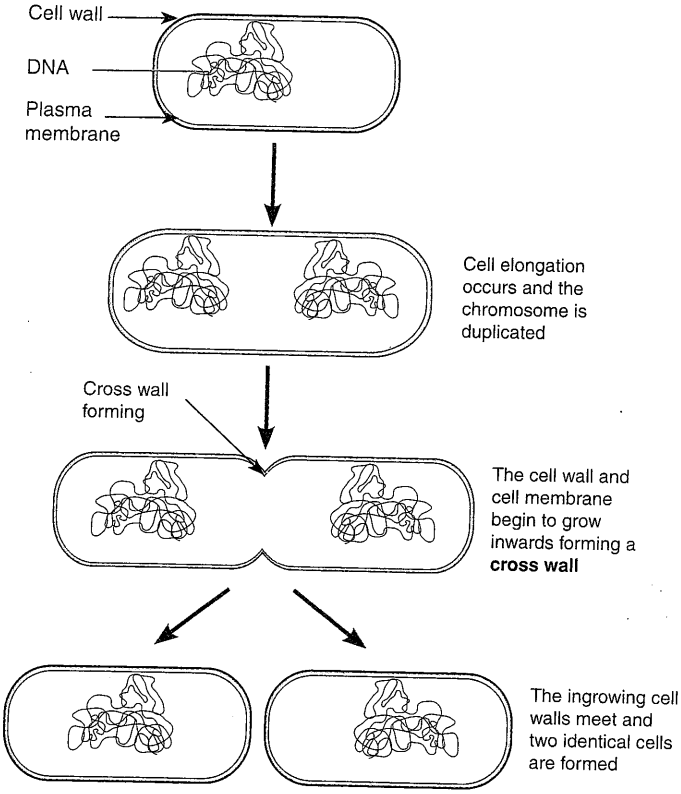
Wadsworth Center, New York State Department of Health

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.

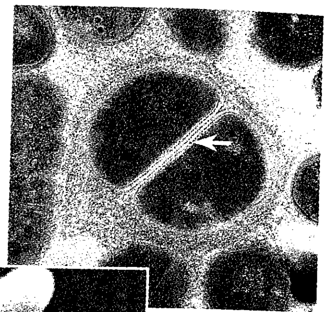
ISBN: 978-1-927173-39-8

Binary Fission

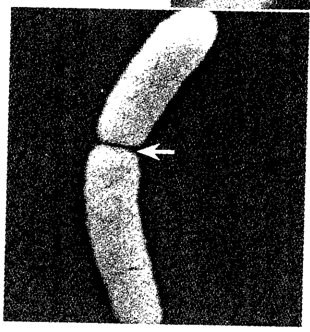
Binary fission is a form of asexual reproduction carried out by most prokaryotes (bacteria and cyanobacteria), in some eukaryotic organelles, such as mitochondria and chloroplasts, and by some unicellular eukaryotes (although the process is somewhat different in eukaryotic cells). In this process, the 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.



This gram positive coccus (right) is in the process of binary fission. A cross wall (arrow) has formed.



CDC

This *Salmonella typhimurium* bacterium (left) has completed cell division. The separation between the two cells can be clearly seen (arrow).

Generation time (minutes)	Population size
0	1
20	2
40	4
60	8
80	
100	
120	
140	
160	
180	
200	
220	
240	
260	
280	
300	
320	
340	
360	

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: ______

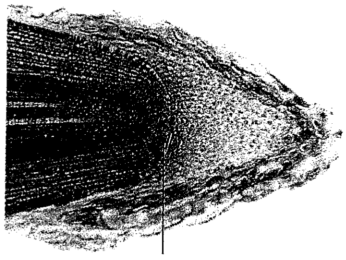
ISBN: 978-1-927173-39-8

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

❶ 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**.



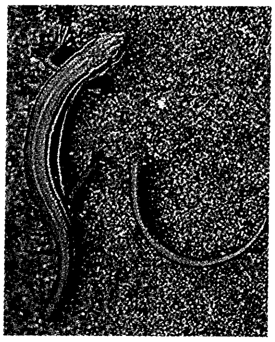


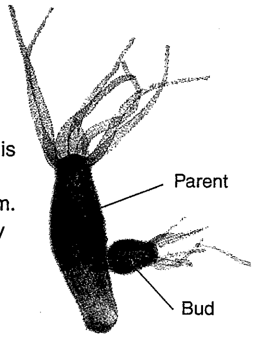
Photo: AB Sheldon

❷ 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.

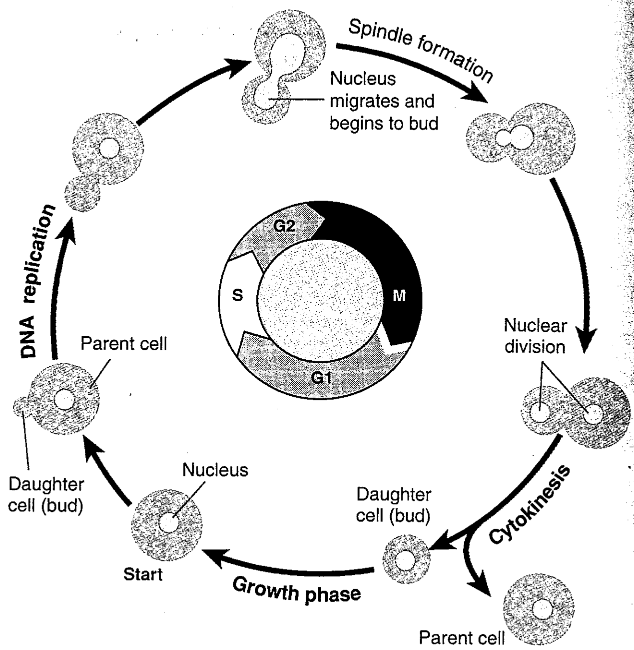
❸ Reproduction

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.

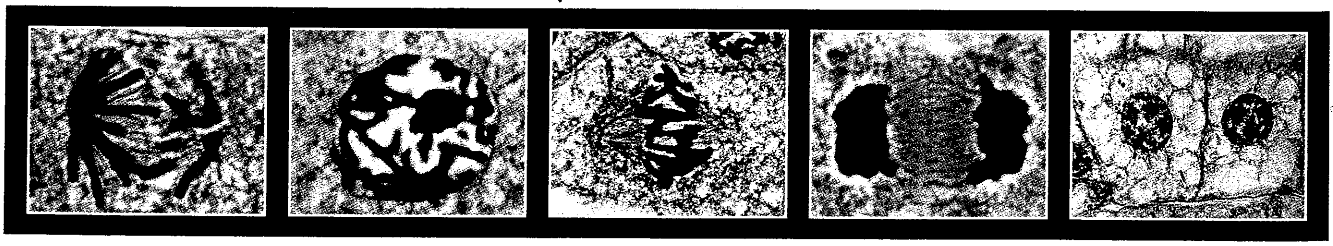


The Budding Yeast Cell Cycle

Yeasts can reproduce asexually through **budding**. In *Saccharomyces cerevisiae* (baker's yeast), budding involves mitotic division in the parent cell, with the formation of a daughter cell (or bud). As budding begins, a ring of chitin stabilises the area where the bud will appear and enzymatic activity and turgor pressure act to weaken and extrude the cell wall. New cell wall material is incorporated during this phase. The nucleus of the parent cell also divides in two, to form a daughter nucleus, which migrates into the bud. The daughter cell is genetically identical to its parent cell and continues to grow, eventually separating from the parent cell.



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).



(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. ____

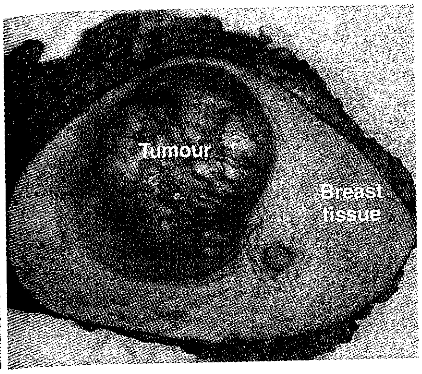
E. ____

F. ____

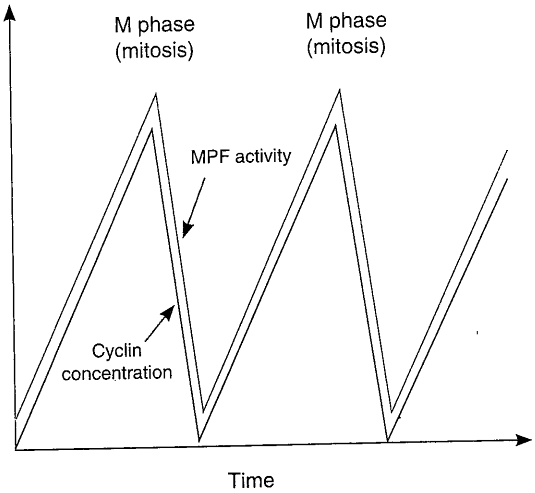
ISBN: 978-1-927173-39-8

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.



Regulation of the cell cycle is important in detecting and repairing of genetic damage, and preventing uncontrolled cell division. Tumours and cancers, such as this breast cancer (above) are the result of uncontrolled cell division.



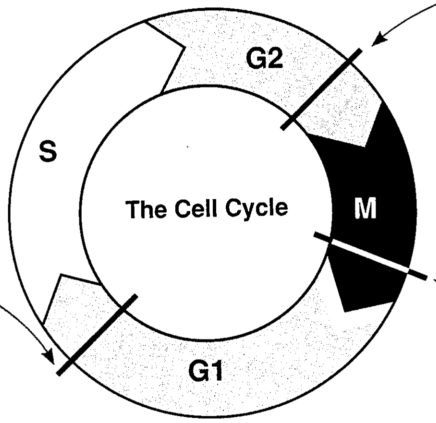
A substance called an M-phase promoting factor (MPF) controls cell regulation. MPF is made up of two regulatory molecules, **cyclins** and **cyclin-dependent kinases** (CDKs).

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 G_1 checkpoint.



G_2 Checkpoint:
Pass this checkpoint if:
- Cell size is large enough.
- Replication of chromosomes has been successfully completed.

G_1 checkpoint
Pass this checkpoint if:
- Cell size is large enough.
- Sufficient nutrients are available.
- Signals from other cells have been received.

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? ____________________

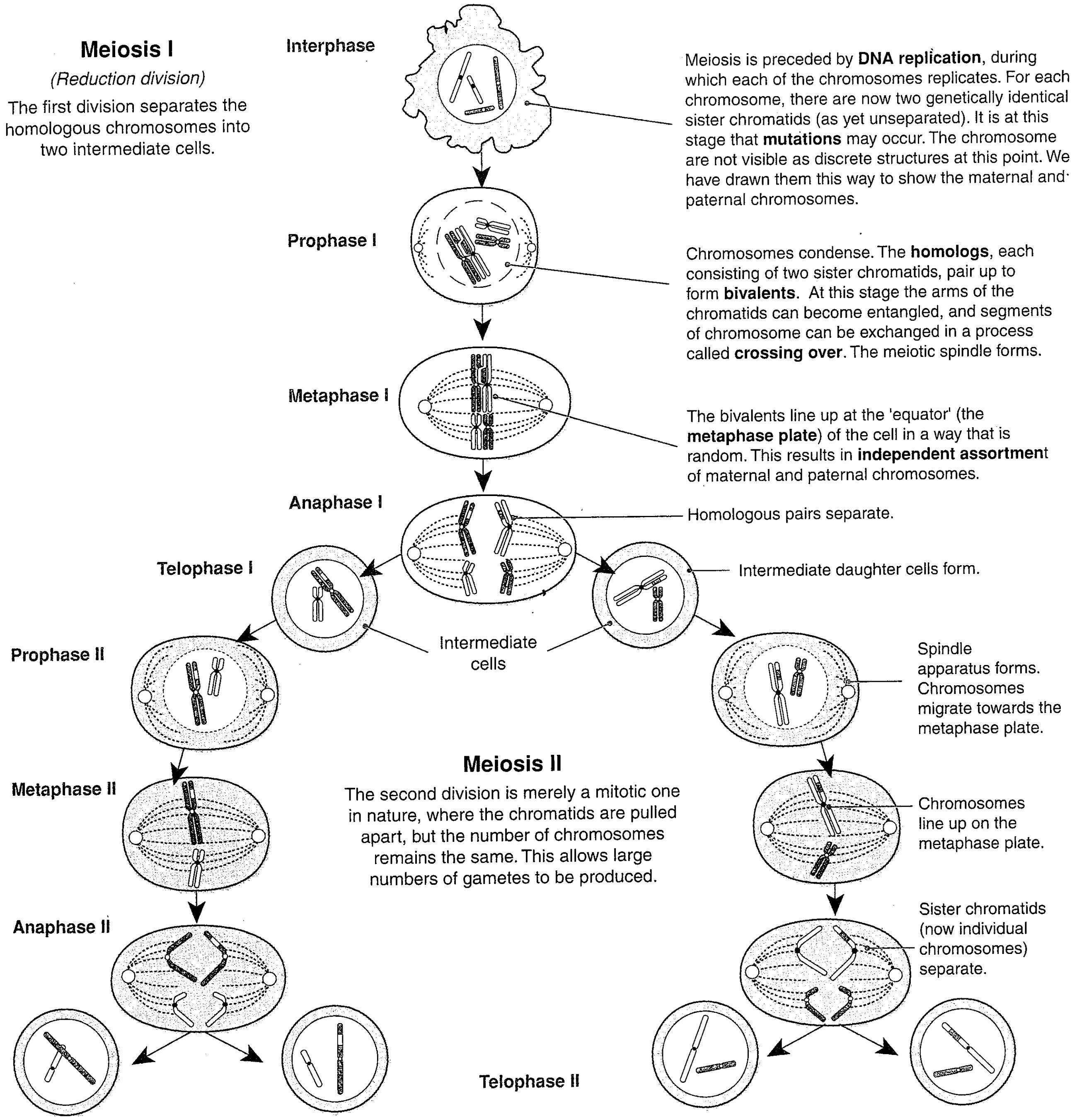
2. (a) Suggest why the cell cycle is shorter in epithelial cells (such as intestinal cells) than in liver cells:

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

ISBN: 978-1-927173-39-8

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).



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

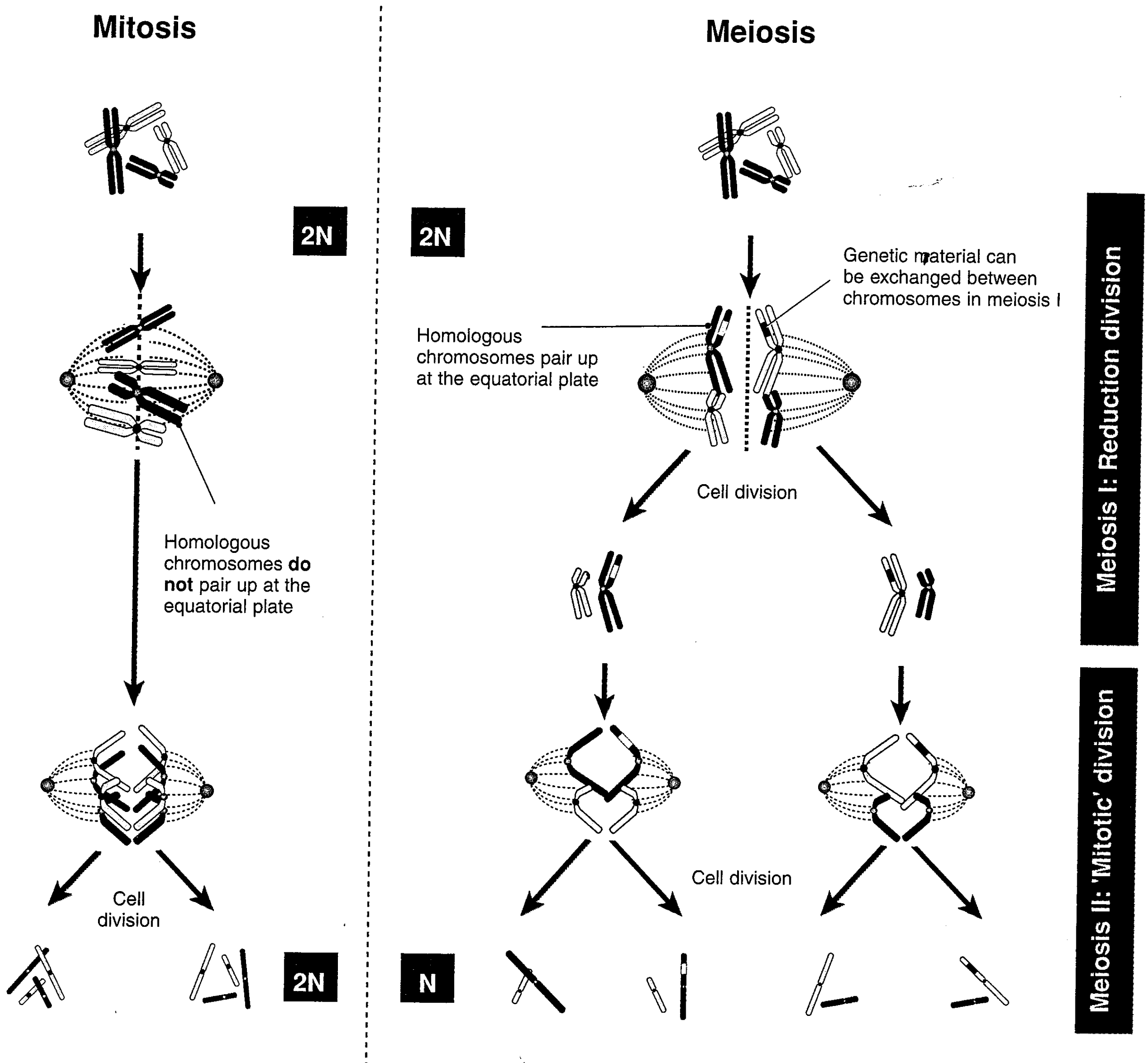
2. Describe the behaviour of the chromosomes in the second division of meiosis: ______________________

ISBN: 978-1-927173-39-8

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.



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)?

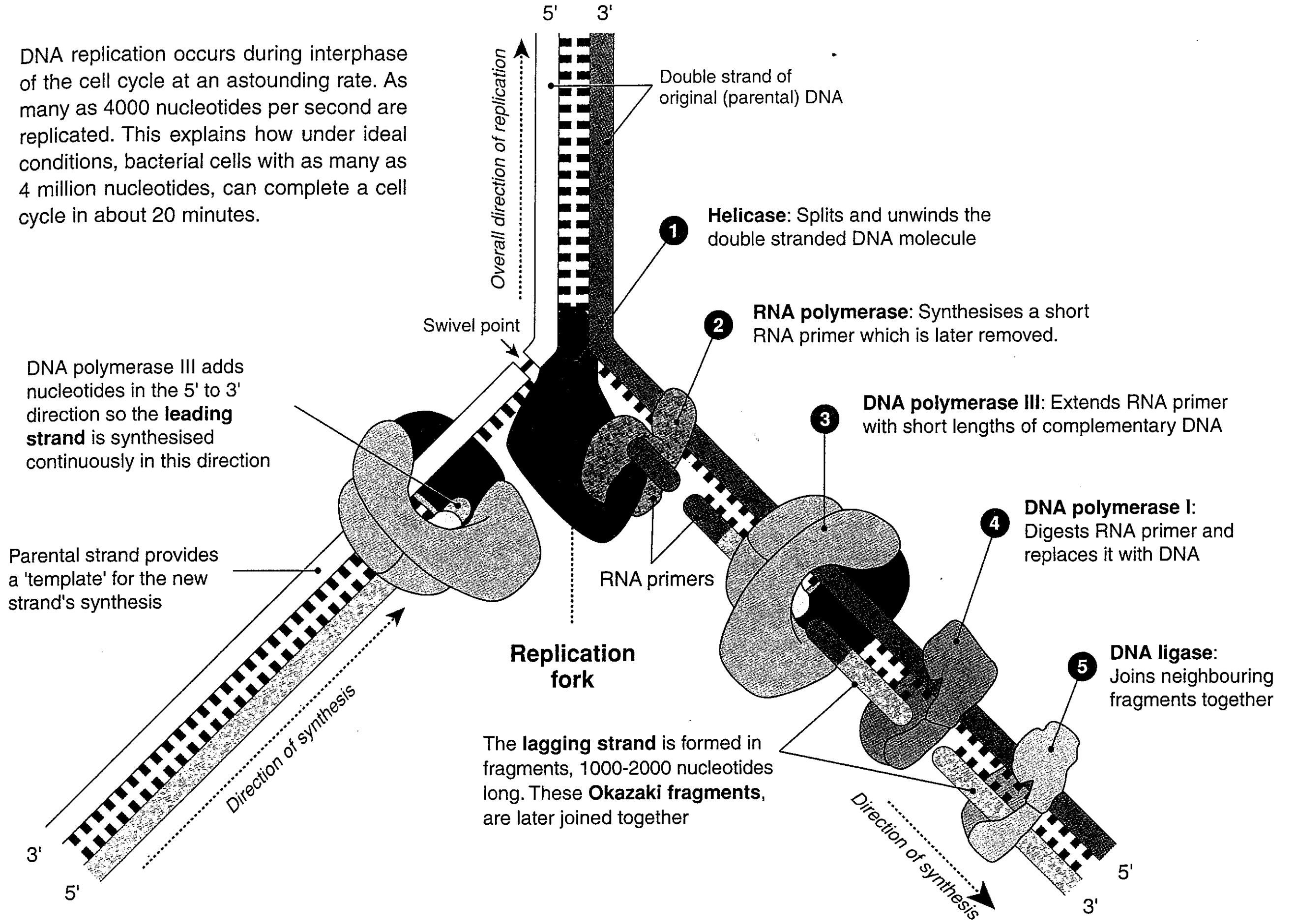
Related activities: *Mitosis and the Cell Cycle, Meiosis*

ISBN: 978-1-927173-39-8

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 deoxynucleoside triphosphates. When hydrolysed, these provide the energy for incorporating the nucleotide into the strand.

DNA replication occurs during interphase of the cell cycle at an astounding rate. As many as 4000 nucleotides per second are replicated. This explains how under ideal conditions, bacterial cells with as many as 4 million nucleotides, can complete a cell cycle in about 20 minutes.



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): ______________

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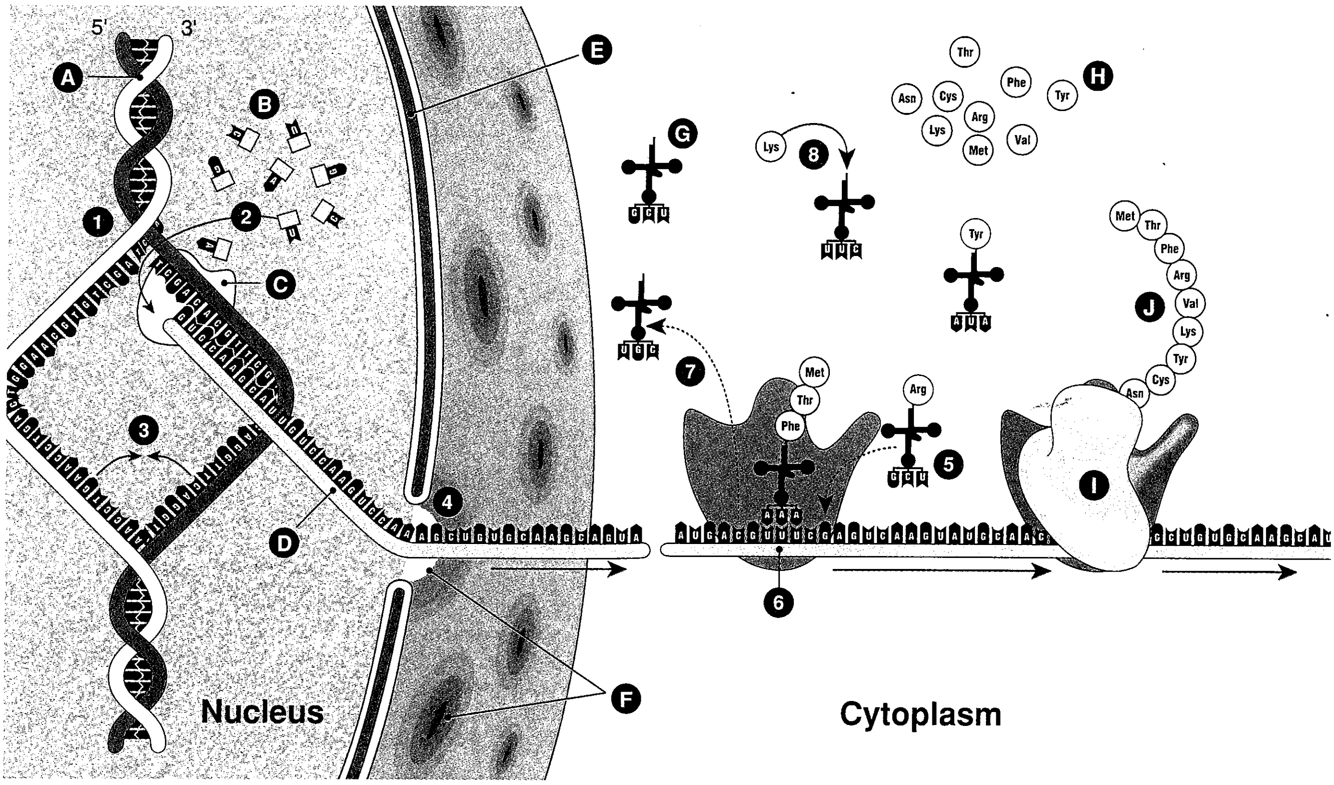
Related activities: *DNA Replication*

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: ______ (f) Structure F: ______

   (b) Structure B: ______ (g) Structure G: ______

   (c) Structure C: ______ (h) Structure H: ______

   (d) Structure D: ______ (i) Structure I: ______

   (e) Structure E: ______ (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 expression

ISBN: 978-1-927173-39-8

KEY TERMS: Mix and Match

INSTRUCTIONS: Test your vocabulary by matching each term to its correct definition, as identified by its preceding letter code.

Term		Definition
allele	A	Single stranded nucleic acid that consists of nucleotides that contain ribose sugar.
anticodon	B	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.
autosome	C	The process by which genetic information is used to produce a functional gene product.
base-pairing rule	D	A set of rules by which information encoded in DNA or mRNA is translated into proteins.
chromatid	E	The rule governing the pairing of complementary bases in DNA.
chromosome	F	The region of a transfer RNA with a sequence of three bases that are complementary to a codon in the messenger RNA.
coding strand	G	DNA regions within a gene that are not translated into protein.
diploid	H	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.
DNA	I	The number and appearance of chromosomes in the nucleus of a eukaryotic cell.
exons	J	The process of creating an equivalent RNA copy of a sequence of DNA.
gene expression	K	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.
genetic code	L	Form of intermolecular bonding between hydrogen and an electronegative atom such as oxygen.
hydrogen bonding	M	The sequence of DNA that is read during the synthesis of mRNA.
introns	N	Universally found macromolecules composed of chains of nucleotides. These molecules carry genetic information within cells.
karyotype	O	The DNA strand with the same base sequence as the RNA transcript produced (although with thymine replaced by uracil in mRNA).
nucleic acids	P	A non-sex chromosome.
nucleotides	Q	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.
protein	R	The structural units of nucleic acids, DNA and RNA.
purine	S	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.
pyrimidine	T	Having two homologous copies of each chromosome (2N), usually one from the mother and one from the father.
RNA (mRNA, rRNA, tRNA)	U	Nucleic acid sequences that are represented in the mature form of an RNA molecule.
sex chromosome	V	The chromosome that carries the gene for determination of sex in individual organisms.
template strand	W	The stage of gene expression in which mRNA is decoded to produce a polypeptide.
transcription	X	One of a pair of duplicated chromosomes produced prior to cell division, joined at the centromere.
translation	Y	One of a number of alternative versions of a gene that can occupy a given genetic locus on a chromosome.

DNA and the Genetic Code

ISBN: 978-1-927173-39-8