Chapter 10: Cell Cycle and Cell Division

Exercises — Exercises

Q1 What is the average cell cycle span for a mammalian cell?

SOLUTION

The average duration of the cell cycle for a typical mammalian cell grown in culture is approximately 24 hours.

Of this total, the M phase (actual cell division) lasts only about 1 hour, while the interphase occupies more than 95% of the cycle — roughly 23 hours.

Answer: Approximately 24 hours for a typical mammalian cell in culture, with interphase occupying more than 95% of that time.

Q2 Distinguish cytokinesis from karyokinesis.

SOLUTION

Karyokinesis:

1. It is the division of the nucleus.
2. It involves the separation and distribution of duplicated chromosomes (DNA) into two daughter nuclei.
3. It encompasses the four stages: prophase, metaphase, anaphase, and telophase.
4. It precedes cytokinesis.

Cytokinesis:

1. It is the division of the cytoplasm.
2. It results in the physical splitting of one parental cell into two daughter cells.
3. In animal cells, it occurs by cleavage furrow formation (inward pinching of the plasma membrane).
4. In plant cells, it occurs by cell-plate formation that grows outward from the centre to meet the lateral walls.
5. It follows karyokinesis to complete cell division.

Note: In some organisms karyokinesis occurs without cytokinesis, producing multinucleate cells called syncytia (e.g., liquid endosperm of coconut).

Answer: Karyokinesis = nuclear division (segregation of chromosomes into two nuclei); cytokinesis = cytoplasmic division that physically separates the two daughter cells. Cytokinesis follows karyokinesis.

Q3 Describe the events taking place during interphase.

SOLUTION

Interphase is the preparatory phase between two successive M phases. Though called the 'resting phase', the cell is highly metabolically active. It comprises three sub-phases:

G1 phase (Gap 1 / First Growth phase):
- Corresponds to the interval between the end of the previous M phase and the start of DNA replication.
- The cell grows in size; metabolic activity is high.
- Organelle duplication (other than centrioles) occurs.
- DNA is NOT yet replicated.
- Cells that exit the cycle permanently enter the G0 (quiescent) stage from here.

S phase (Synthesis phase):
- DNA replication (synthesis) takes place; the amount of DNA per cell doubles from 2C to 4C.
- Chromosome number remains the same (2n — no new chromosomes are added; each chromosome now consists of two identical sister chromatids).
- In animal cells, centrioles also duplicate during this phase.

G2 phase (Gap 2 / Second Growth phase):
- DNA replication is complete; the cell checks for errors.
- Proteins required for mitosis (e.g., tubulin for spindle fibres) are synthesised.
- Cell growth continues in preparation for division.

Answer: Interphase has three phases — G1 (cell growth, no DNA replication), S (DNA replication, DNA doubles from 2C to 4C, centriole duplication in animal cells), and G2 (protein synthesis for mitosis, further cell growth). The cell prepares for division throughout.

Q4 What is G0 (quiescent phase) of cell cycle?

SOLUTION

Some cells in adult animals do not appear to divide or divide only occasionally. These cells exit the G1 phase and enter an inactive stage called the quiescent stage or G0 phase.

Key features of G0:
- Cells remain metabolically active but no longer proliferate.
- They have stopped dividing indefinitely unless signalled to re-enter the cell cycle.
- They re-enter the cycle only when required by the organism (e.g., to replace cells lost due to injury or cell death).

Examples: Many neurons, cardiac muscle cells, and certain liver cells are in the G0 phase in adult animals.

Answer: G0 (quiescent phase) is an inactive stage that cells enter from G1 when they stop dividing. The cells remain metabolically active but do not proliferate, and may re-enter the cycle when the organism requires cell replacement.

Q5 Why is mitosis called equational division?

SOLUTION

Mitosis is called equational division because the chromosome number of the parent cell is exactly preserved in both daughter cells — the number remains equal throughout.

During mitosis:
- Each chromosome replicates to form two sister chromatids during S phase.
- At anaphase, centromeres split and sister chromatids separate and move to opposite poles.
- Each daughter nucleus receives one complete set of chromosomes identical to the parent cell.

Result: If the parent cell is diploid (2n), both daughter cells are also diploid (2n). There is NO reduction in chromosome number. The daughter cells are genetically identical to the parent cell (barring mutations).

Answer: Mitosis is called equational division because the chromosome number remains equal in parent and daughter cells — a 2n parent gives two 2n daughters, with no reduction in chromosome number.

Q6 Name the stage of cell cycle at which one of the following events occur: (i) Chromosomes are moved to spindle equator. (ii) Centromere splits and chromatids separate. (iii) Pairing between homologous chromosomes takes place. (iv) Crossing over between homologous chromosomes takes place.

SOLUTION

(i) Chromosomes are moved to spindle equator — Metaphase (of mitosis) / Metaphase I (of meiosis I).

During metaphase, spindle fibres attached to kinetochores align all chromosomes at the equatorial plate (metaphase plate).

(ii) Centromere splits and chromatids separate — Anaphase (of mitosis) / Anaphase II (of meiosis II).

At the onset of anaphase the centromere of each chromosome splits simultaneously, allowing sister chromatids to move to opposite poles.

(iii) Pairing between homologous chromosomes takes place — Zygotene (sub-stage of Prophase I of meiosis I).

During zygotene, homologous chromosomes start pairing in a process called synapsis, accompanied by the formation of the synaptonemal complex.

(iv) Crossing over between homologous chromosomes takes place — Pachytene (sub-stage of Prophase I of meiosis I).

Recombination nodules appear at pachytene and the enzyme recombinase catalyses the exchange of genetic material (crossing over) between non-sister chromatids of homologous chromosomes.

Answer: (i) Metaphase; (ii) Anaphase (mitosis) / Anaphase II (meiosis); (iii) Zygotene of Prophase I; (iv) Pachytene of Prophase I.

Q7 Describe the following: (a) synapsis (b) bivalent (c) chiasmata. Draw a diagram to illustrate your answer.

SOLUTION

(a) Synapsis:

Synapsis is the pairing of homologous chromosomes during the zygotene sub-stage of Prophase I of meiosis I. Each pair of homologous chromosomes comes to lie side by side along their entire length. The pairing is precise and gene-to-gene. It is accompanied by the formation of a ribbon-like proteinaceous structure called the synaptonemal complex between the two homologues, which holds them together.

(b) Bivalent (Tetrad):

The complex formed by a pair of synapsed homologous chromosomes is called a bivalent (because it consists of 2 homologues). Since each homologue at this stage is made up of 2 chromatids, the bivalent contains 4 chromatids in total and is also referred to as a tetrad. Bivalents are clearly visible from the pachytene stage onwards.

(c) Chiasmata:

During diplotene, the synaptonemal complex dissolves and the paired homologous chromosomes tend to separate from each other. However, they remain attached at specific points where crossing over had occurred during pachytene. These X-shaped attachment points are called chiasmata (singular: chiasma). Each chiasma represents the physical manifestation of a crossover event. They move toward the chromosome ends (terminalisation) during diakinesis.

Diagram description (labelled sketch of a bivalent at diplotene/diakinesis):

Draw two homologous chromosomes (each consisting of two chromatids) held together at one or more X-shaped points. Label the following:

- Centromere: the constriction point at the centre of each chromosome
- Sister chromatids: the two chromatids of the same homologue (connected at centromere)
- Non-sister chromatids: one chromatid from each homologue that participated in crossing over
- Chiasma (X-shaped junction): the point of crossover between two non-sister chromatids
- Bivalent / Tetrad: the entire four-chromatid structure

- Synaptonemal complex (shown at zygotene stage): the proteinaceous ladder-like structure between the two homologues

Answer: Synapsis = gene-to-gene pairing of homologous chromosomes at zygotene via the synaptonemal complex. Bivalent (tetrad) = the paired structure of 2 homologues (4 chromatids total). Chiasmata = X-shaped structures at sites of crossing over seen from diplotene onwards, representing recombination points between non-sister chromatids.

Q8 How does cytokinesis in plant cells differ from that in animal cells?

SOLUTION

Cytokinesis in Animal Cells:

1. Animal cells are surrounded only by a flexible plasma membrane.
2. Cytokinesis occurs by the formation of a cleavage furrow — an inward constriction of the plasma membrane at the equatorial region.
3. The furrow gradually deepens and pinches inward until the cytoplasm is divided into two daughter cells.
4. This process is driven by a contractile ring of actin and myosin filaments just beneath the plasma membrane.

Cytokinesis in Plant Cells:

1. Plant cells are enclosed by a relatively rigid, inextensible cell wall, so cleavage furrow formation is not possible.
2. Cytokinesis occurs by the formation of a cell plate.
3. The cell plate forms at the centre of the cell and grows outward (centrifugally) to meet the existing lateral walls.
4. It begins with the fusion of Golgi-derived vesicles (containing cell wall components) at the phragmoplast — a barrel-shaped array of microtubules at the equatorial plane.
5. The cell plate eventually becomes the middle lamella between the two new daughter cells, upon which each daughter cell then deposits its own primary cell wall.

Key difference: Animal cells divide by furrowing inward; plant cells divide by building a new wall outward from the centre.

Answer: Animal cells: cytokinesis by cleavage furrow (inward constriction of plasma membrane). Plant cells: cytokinesis by cell-plate formation (Golgi vesicles fuse at the phragmoplast, forming a plate at the centre that grows outward to the lateral walls, becoming the new middle lamella).

Q9 Find examples where the four daughter cells from meiosis are equal in size and where they are found unequal in size.

SOLUTION

Equal-sized daughter cells from meiosis:
Meiosis in male animals (spermatogenesis) produces four equal-sized spermatids from a primary spermatocyte. These differentiate into four functional spermatozoa.
Similarly, meiosis in pollen mother cells (microspore mother cells) of plants produces four equal-sized microspores arranged in a tetrad.

Unequal-sized daughter cells from meiosis:
Meiosis in female animals (oogenesis) produces unequal cells:
- Meiosis I of a primary oocyte gives a large secondary oocyte and a small, non-functional first polar body.
- Meiosis II of the secondary oocyte gives one large ootid (which matures into the egg / ovum) and a small, non-functional second polar body.
- The first polar body may also divide to give two more tiny polar bodies.
Thus, from oogenesis, one large functional egg cell and three tiny non-functional polar bodies are produced.

Summary: Equal-sized — spermatogenesis (animals), microspore formation (plants). Unequal-sized — oogenesis (animals).

Answer: Equal size: spermatogenesis (four equal spermatids) and microspore formation in plants (four equal microspores). Unequal size: oogenesis — one large egg and three small, non-functional polar bodies.

Q10 Distinguish anaphase of mitosis from anaphase I of meiosis.

SOLUTION

Anaphase of Mitosis:
1. The centromere of each chromosome splits, separating the two sister chromatids.

2. Sister chromatids (now called daughter chromosomes) move to opposite poles.
3. The number of chromosomes moving to each pole equals the original chromosome number of the cell (e.g., 2n chromosomes move to each pole in a diploid cell).
4. Each migrating chromosome consists of a single chromatid.
5. Results in two groups of chromosomes, each identical in number and composition to the parent cell — chromosome number is maintained.

Anaphase I of Meiosis:
1. The centromere does NOT split; sister chromatids remain attached at their centromeres.
2. Homologous chromosomes (each still consisting of two sister chromatids) separate and move to opposite poles.
3. The number of chromosomes moving to each pole is half the original number (n chromosomes, each with 2 chromatids, move to each pole).
4. Each migrating unit is a dyad (a chromosome with two chromatids).
5. Results in two groups of chromosomes, each with half the chromosome number of the parent — chromosome number is reduced by half.

Key distinction: In mitotic anaphase, centromeres split and chromatids separate. In meiotic anaphase I, centromeres do NOT split and whole homologues (each with 2 chromatids) separate.

Answer: Mitotic anaphase: centromere splits, sister chromatids separate; each pole receives the full chromosome number (2n). Meiotic anaphase I: centromere does NOT split, intact homologous chromosomes (each with 2 chromatids) separate; each pole receives half the chromosome number (n).

Q11 List the main differences between mitosis and meiosis.

SOLUTION

1. Type of cell division:
   Mitosis: Equational division — chromosome number is maintained.
   Meiosis: Reductional division — chromosome number is halved.

2. Where it occurs:
   Mitosis: Somatic (body) cells; also in meristematic cells of plants.
   Meiosis: Only in reproductive cells (gonads/sporogenous tissue) during gametogenesis or sporogenesis.

3. Number of divisions:
Mitosis: One round of nuclear and cell division.
Meiosis: Two sequential rounds of nuclear and cell division (Meiosis I and Meiosis II).

4. DNA replication:
Mitosis: One round of DNA replication precedes division.
Meiosis: One round of DNA replication precedes two divisions; NO DNA replication occurs between Meiosis I and Meiosis II.

5. Pairing of homologous chromosomes:
Mitosis: No pairing (synapsis) of homologues occurs.
Meiosis: Homologous chromosomes pair during Prophase I (synapsis).

6. Crossing over:
Mitosis: Does not occur.
Meiosis: Occurs between non-sister chromatids of homologous chromosomes at pachytene of Prophase I.

7. Duration of Prophase:
Mitosis: Prophase is relatively short.
Meiosis: Prophase I is very long and complex (subdivided into leptotene, zygotene, pachytene, diplotene, diakinesis).

8. Chiasmata:
Mitosis: Absent.
Meiosis: Present (at diplotene/diakinesis of Prophase I).

9. Number of daughter cells:
Mitosis: Two daughter cells.
Meiosis: Four daughter cells.

10. Chromosome number in daughter cells:
Mitosis: Equal to parent cell (2n -> 2n + 2n).
Meiosis: Half the parent cell (2n -> n + n + n + n).

11. Genetic composition of daughter cells:
Mitosis: Genetically identical to parent (clones).
Meiosis: Genetically different due to crossing over and independent assortment.

Answer: Key differences: Mitosis = 1 division, 2 identical diploid daughters, no synapsis/crossing over, equational. Meiosis = 2 divisions, 4 haploid daughters, synapsis + crossing over in Prophase I, reductional. Only one DNA replication precedes both meiotic divisions.

Q12 What is the significance of meiosis?

SOLUTION

1. Conservation of chromosome number across generations:
Meiosis halves the chromosome number during gamete formation. When two gametes fuse at fertilisation, the diploid number is restored. Without meiosis, chromosome numbers would double every generation.

2. Production of haploid gametes:
Meiosis is essential for the production of haploid gametes (eggs and sperm in animals; spores in plants) needed for sexual reproduction.

3. Genetic variation through crossing over:
During pachytene of Prophase I, crossing over between non-sister chromatids of homologous chromosomes leads to recombination of genetic material. This generates new combinations of alleles on chromosomes, creating genetic diversity.

4. Genetic variation through independent assortment:
During Metaphase I, homologous pairs align independently at the equatorial plate, resulting in random distribution of maternal and paternal chromosomes to daughter cells. This further increases genetic variability.

5. Raw material for evolution:
The genetic variations produced by meiosis provide the raw material for natural selection and evolution. Variations that are beneficial are selected and propagated through generations.

6. Maintenance of species identity:
By ensuring a fixed haploid chromosome number in gametes, meiosis maintains the characteristic chromosome number of a species from generation to generation.

Answer: Meiosis conserves the species chromosome number across sexual generations, produces haploid gametes for fertilisation, and generates genetic variability through crossing over and independent assortment — providing raw material for evolution.

Q13 Discuss with your teacher about (i) haploid insects and lower plants where cell-division occurs, and (ii) some haploid cells in higher plants where cell-division does not occur.

SOLUTION

This question requires discussion with a teacher. The following points provide a basis for that discussion:

(i) Haploid organisms/cells that undergo cell division:
- Male honey bees (drones) are haploid (produced by parthenogenesis from unfertilised eggs). Their somatic cells divide by mitosis, demonstrating that mitosis can occur in haploid cells in animals.
- In lower plants (bryophytes and pteridophytes), the gametophyte generation is haploid and its cells divide by mitosis to produce a multicellular gametophyte. For example, in mosses, the protonema (haploid) divides mitotically.
- In algae (e.g., Spirogyra), cells are haploid and divide by mitosis for vegetative growth.

(ii) Haploid cells in higher plants that do NOT divide:
- In angiosperms (higher plants), the female gametophyte is highly reduced. For example, the egg cell (n), synergids (n), and antipodal cells (n) within the embryo sac are haploid cells that have lost the ability to divide under normal conditions (they are terminally differentiated).
- Pollen grains (microspores) are haploid but after germination the generative nucleus divides only once (to produce two male gametes); the pollen tube cell (n) itself does not undergo further division.
- Thus in higher plants, the gametophytic generation is reduced to a few non-dividing haploid cells.

Answer: Haploid cells that DO divide by mitosis: male honey bees (drones), haploid gametophytes of bryophytes and pteridophytes, haploid algae. Haploid cells that do NOT divide: egg cell, synergids, and antipodal cells of the angiosperm embryo sac (terminally differentiated).

Q14 Can there be mitosis without DNA replication in 'S' phase?

SOLUTION

No. Under normal circumstances, mitosis cannot occur without prior DNA replication during the S phase.

Reason: The fundamental purpose of mitosis is to distribute an exact, complete copy of the genome to each daughter cell. For this to happen, every chromosome must first be duplicated so that two identical sister chromatids are available — one for each daughter cell. DNA replication in the S phase produces these sister chromatids.

If S phase is artificially blocked (e.g., by hydroxyurea that inhibits ribonucleotide reductase), cells arrest at the G1/S boundary and do not proceed to mitosis.

If, hypothetically, mitosis occurred without DNA replication, each daughter cell would receive only half the genetic information of the parent — an outcome incompatible with life for most cells.

Therefore, S phase DNA replication is an obligatory prerequisite for mitosis. The cell cycle checkpoints (especially the G1/S and G2/M checkpoints) ensure that mitosis does not begin until DNA replication is complete and accurate.

Answer: No. DNA replication in S phase is an obligatory prerequisite for mitosis. Without it, sister chromatids would not be available and each daughter cell would receive only half the genome, which is incompatible with normal cell function.

Q15 Can there be DNA replication without cell division?

SOLUTION

Yes. DNA replication can occur without being followed by cell division.

Examples and situations:
1. Polytene chromosomes: In certain cells (e.g., salivary gland cells of Drosophila larvae), DNA replicates repeatedly without cell division, producing chromosomes with hundreds of chromatid copies side by side (polyteny).
2. Polyploidisation: In some plant cells, DNA replication without subsequent cell division leads to polyploidy — an increase in DNA content without an increase in cell number.
3. Endoreduplication: Some cells undergo repeated rounds of S phase without entering mitosis, resulting in cells with very high DNA content.

4. DNA repair synthesis: Small patches of DNA are replicated locally during repair processes (e.g., in nucleotide excision repair), without triggering full S phase or cell division.
5. Cells in G0: A cell can replicate DNA and enter S phase if stimulated, but if cell cycle progression is halted at a checkpoint (e.g., G2/M) after replication, division may not follow.

Conclusion: DNA replication is essential for cell division, but the reverse is not true — replication can proceed without division.

Answer: Yes. DNA replication can occur without cell division — examples include polyteny (salivary gland cells of Drosophila), endoreduplication in plants, and DNA repair synthesis. Replication is a prerequisite for division, but division is not an obligatory consequence of replication.

Q16 Analyse the events during every stage of cell cycle and notice how the following two parameters change: (i) number of chromosomes (N) per cell (ii) amount of DNA content (C) per cell

SOLUTION

Assume the starting cell is diploid: 2N chromosomes and 2C DNA content (at the beginning of G1 after the previous M phase).

G1 phase:
- Chromosome number: 2N (unchanged)
- DNA content: 2C (unchanged; no replication yet)

S phase (DNA replication):
- Chromosome number: 2N (unchanged — each chromosome now has 2 chromatids but they are still counted as one chromosome per centromere)
- DNA content: increases progressively from 2C to 4C by end of S phase

G2 phase:
- Chromosome number: 2N (unchanged)
- DNA content: 4C (unchanged; replication complete)

Prophase (Mitosis):
- Chromosome number: 2N
- DNA content: 4C

Metaphase (Mitosis):

- Chromosome number: 2N
- DNA content: 4C

Anaphase (Mitosis — centromeres split):
- Chromosome number: 4N (centromere splitting doubles the count — sister chromatids now become individual chromosomes)
- DNA content: 4C (no change in total DNA; it is redistributed)

Telophase / Cytokinesis (end of M phase — each daughter cell):
- Chromosome number: 2N (each daughter cell receives 2N chromosomes)
- DNA content: 2C (each daughter cell receives 2C DNA)

For Meiosis (starting with a 2N, 2C cell after S phase = 2N chromosomes, 4C DNA):
After Meiosis I (Anaphase I — homologues separate):
- Each secondary cell: N chromosomes (each with 2 chromatids), 2C DNA
After Meiosis II (Anaphase II — centromeres split, chromatids separate):
- Each cell: 2N chromosomes momentarily, then each daughter receives N chromosomes, 1C DNA

Answer: In mitosis: G1 = 2N / 2C; S phase end = 2N / 4C; G2 = 2N / 4C; Anaphase (peak) = 4N / 4C; each daughter cell after cytokinesis = 2N / 2C. DNA doubles in S phase; chromosome count momentarily doubles at anaphase when centromeres split, then halves in each daughter cell.