10. Cell Cycle and Cell Division

Cell division (mitosis) was first studied by Strasburger in plant and Flemming in animal. Term of mitosis was coined by Flemming. Term of meiosis was coined by Farmer and Moore. Meiosis was studied by Sutton, Strasburger. Meiosis I & II were differentiated by Gregoire.

1. Time Period of Cell Cycle

Time interval between two successive divisions is called generation time. Duration of cell cycle differs cell to cell. Example 24 hrs in human somatic cell, 90 min. in yeast. However , in an average duration of 24 hours, dividing phase lasts for about an hour,i.e. 5% of the cell cycle and interphase lasts for almost 23 hours, i.e. more than 95% of the duration of the cell cycle.

2. Phases of Cell Cycle

Cell cycle was given by Howard & Pele in 1953 by using autoradiography in Vicia faba. It is a series of cyclic changes by which cell duplicated its components and divides into two. Sequence of events is genetically controlled. A cell cycle has two phases, i.e. Interphase and M-phase. Both of these phases have their own sub stages.

3. Substages of Cell Cycle

3.1. Interphase (I-Phase)

Longest (95% of total cell cycle). Intermitosis /preparatory /energy or metabolic phase is cytologically resting but physiologically most active. It occurs in a newly formed cell before it is able to divide. Interphase has following stages-

(1) G_1-Phase (First growth or Gap phase, Pre-synthetic phase):

It is the Longest phase of cell cycle but most variable in length. Cell and nucleus grow in size. In middle of G_1 phase (Restriction point) a cell has two options. Stop cell cycle and enter G_0 phase for undergoing differentiation or Continue cycle and enter S-phase by taking decision of division with the help of growth-dependent cyclin-dependent kinase (CDK). It's activity promotes DNA replication and initiates G1-to-S phase transition. There is synthesis of RNAs, proteins (non histone, non tubulin), enzymes for DNA synthesis, and amino acids for histone formation, nucleotides and ATP. Cell organelles also increase in number. Storage of ATP takes in G_1. The stage where this decision is takes place called check point. Duration of G_1 phase is longer in cells dividing infrequently. It is shorter in frequently dividing cells.

(2) G_0-Phase or Quiescent stage (By Lajtha):

Phase of cell differentiation where cell cycle is stopped in middle of G_1-phase due to activation of some genes. They allow cell to grow to a particular size, shape and come to perform some specific functions.In this phase cell remains metabolically active but does not divide unless called on to do so. Ex: Nerve cell, muscle cell, RBC and WBC always remain in G_0 phase of cell cycle.

(3) S-Phase (Synthetic phase):

In this phase the cell synthesizes a replica of its genome, by the process of DNA replication This phase also includes the synthesis of histone proteins and kinetochores. Thus, DNA content becomes doubled.

(4) G_2-Phase (Growth II, Post-Synthetic, Pre-mitotic, Smallest phase):

There is again synthesis of proteins (non histone) and RNAs. Cell size double. Cell organelles increase in number. Protein tubulin is formed. Damaged DNA is repaired and cyclins kinase proteins (Cyclin-dependent kinase protein= CDCK) are synthesized for regulation of cell division. Cyclin and kinase cause phosphorylation, dephosphorylation and induce cell to enter into division phase.

3.2. M Phase(Dividing)

Mitotic or M phase follows the interphase. It starts with the nuclear division(karyokinesis), corresponding to the separation of daughter chromosomes and usually ends with division of cytoplasm (Cytokinesis). It is aimed at orderly distribution of the already duplicated chromosomes among the two daughter nuclei.

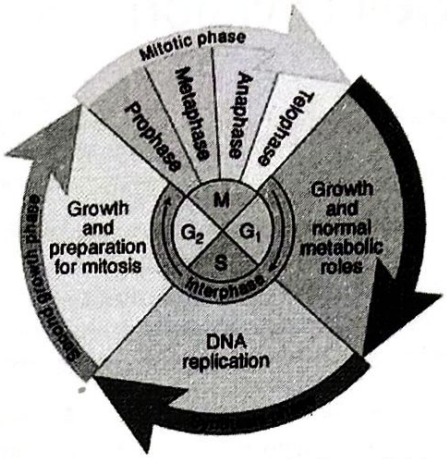
Inducer of cell division:

- The agents which stimulated cell division are called mitogens, e.g. cytokinins, some steroids, epidermal growth factor (EGF), platelet-derived growth factor (PDGF), lymphokines.
- Besides mitogens, cells are stimulated to divide in achieving a particular size, critical decrease in surface volume ratio, critical decrease in nucleocytoplasmic (kernplasma ratio). Some genes also induce cell division. e.g. Cleavage in zygote.

Importance of cell division:

- Cell division is a pre-requisite for the continuity of life and forms the basis of evolution is the means of asexual reproduction to various life forms.
- In multi-cellular organisms, life starts from a single cell called zygote (fertilized egg). The zygote transforms into an adult that is composed of millions of cells formed by successive divisions.

- Cell division is the basis of repair and regeneration of old and worn out tissues.



Cell Divisions is of three types- Amitosis (direct division), mitosis (indirect division) and meiosis (indirect division).

4. Amitosis

It was discovered by Remak in (1841) in the red blood cells of chick embryo and later studied by Flemming in 1882. In this division there is no differentiation of chromosomes and spindle. The nuclear envelope does not degenerate. Nucleus elongates and constricts in the middle to form two daughter nuclei. This is followed by a centripetal constriction of cytoplasm to form two daughter cells.

4.1. Characteristics

(1) The intact nuclear envelope is found throughout the division.

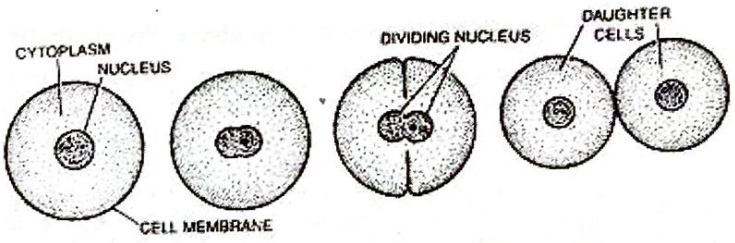
(2) Chromatin does not condense into definite chromosomes.

(3) A spindle is not formed.

(4) Chromatin distribution occurs unequally which causes abnormalities in metabolism and reproduction.

(5) Cytokinesis may or may not follow karyokinesis.

Amitosis occurs in mega-nucleus of *Paramecium*, nuclei of internodal cells of *Chara*, endosperm cells of seeds, cartilage cells and diseased cells.



Stages in amitosis

5. Mitosis (Somatic Cell Division)

It is equational division, in which a cell divides into two identical daughter cells. Each daughter cell has same number and kind of chromosomes as in the parent cell so-called clone.

5.1. Characteristics

(1) Mitosis was first described by a German biologist Eduard Strasburger in the plant cells in 1875 and later studied by Walther Flemming in the animal cells in 1879.

(2) It occurs during formation of somatic or body cells.

(3) Mitosis term was given by Flemming in 1882.

(4) Mitosis is studied in plants in the regions of meristems, e.g. stem tip, root tip. In laboratory studied in root tip of onion.

(5) In animals it is studied in bone marrow, skin, base of nails, etc.

(6) In animals mitosis occurs in diploid cell but in plant occurs in both diploid and haploid Cell.

(7) Mitosis occurs in two steps, karyokinesis and cytokinesis.

5.2. Karyokinesis

It is the stage of nuclear division (indirect nuclear division), which is continuous but is divided into four stages – Prophase, metaphase, anaphase and telophase. There is no clear-cut demarcation between these phases.

(1) Prophase: It is the longest phase of karyokinesis and divided into three sub-stages.

- **Early prophase:** In this stage nuclear membrane and nucleolus are well defined. Chromatin threads are very thin so, ends of chromosome are not distinguishable. In early prophase or spireme stage, chromatin fibres condense through spiralisation to form elongated chromosomes. In this phase chromosomes having high degree of coiling. Maximum condensation occurs in this phase. Viscosity and refractivity of cytoplasm is increased. Animal cells become nearly rounded. Nucleus appears as a ball of wool called spireme stage. The daughter centrosomes start to move away from each other towards their respected pole.
- **Mid-prophase-**In this, chromosomes become further short and vertically split to become dyad, (two chromatids attached to centromere). The centrosomes develop astral rays and migrate farther. Nucleolus degenerates and nuclear envelope starts breaking.

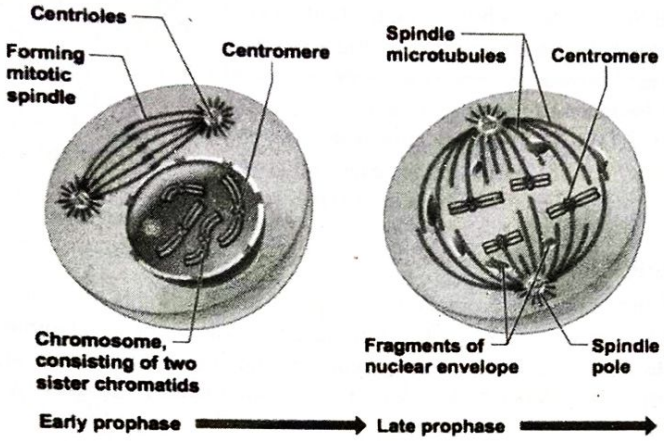
- **Late prophase-**Nuclear envelope disappears. Centrosomes reach nearly at the poles and formation of spindle fibers is started. In plants cells, centrosomes are absent. Spindle fibers develop without them. All organelles disappear except mitochondria and chloroplast. Disappearance of nuclear membrane is indication of termination of prophase

Two types of spindles are formed in the cells:

(a) Amphiastral: In the animal cells, the spindle has an aster at each pole.

(b) Anastral: There are no centrioles in plant cells and no asters are formed.

Prophase Diagram



Important-

Prometaphase-Called second phase by some cytologists. During this nuclear membrane disappears so that nucleoplasm comes in contact with cytoplasm. Chromosomes can move freely in this area. Spindle apparatus or mitotic apparatus gets organized. It can be observed with help of polarizing microscope.

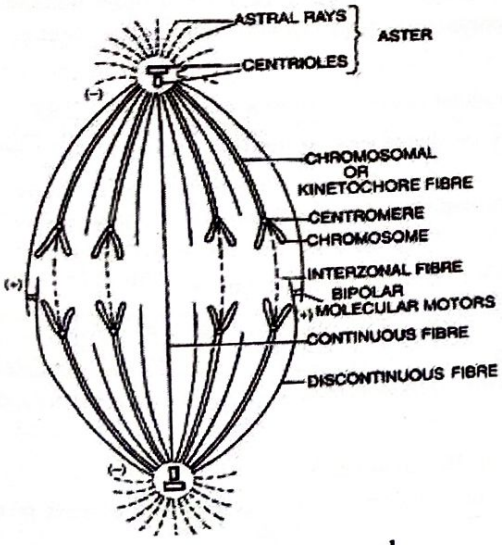
Spindle fibres-A spindle fiber has 4-20 microtubules. Microtubules has minus end towards pole and plus towards equator. Spindle fibres converge at the two ends or poles. Spindle has maximum diameter at equator and minimum at poles. Spindle fibre + aster (astral rays + centrosome)= mitotic apparatus. Fibers of the spindle are of two main types.

a) **Chromosomal:** From pole to centromere of chromosome.

b) **Non-chromosomal:** Not attached to chromosome. These are of two types

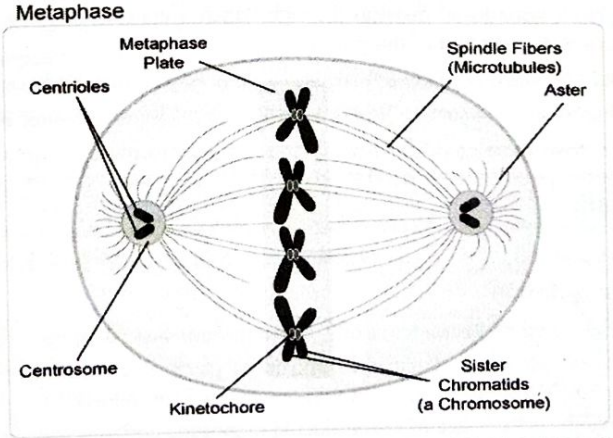
(i) Continuous (from pole to pole).

(ii) Discontinuous (radiating from one pole but not reaching the other). Spindle fiber are made up of sulfur-rich tubulin protein (95%) and RNA (5%).



Chromosomes, asters and spindle in mitotic anaphase

Metaphase



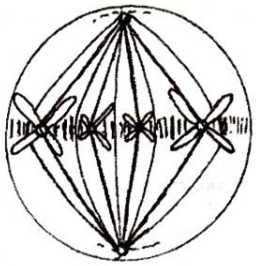
(2) Metaphase:

Chromosomes are shortest (maximum condensed), least coiled at metaphase but thickest in anaphase. Chromosomal fibers contract and bring the chromosomes over the equator. It is called congression (metakinesis). Limbs of chromosomes project in different directions during congression. Centromeres of all the chromosomes are present over the equator. So, chromosomes from an apparent plate called equatorial or metaphasic plate (circular and transverse). It is best time to study chromosomes

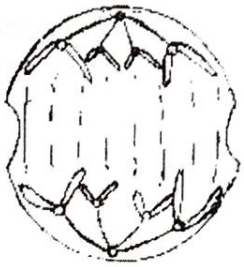
morphology (size, number) but shape is best studied at anaphase. In this stage karyotype and idiogram prepared. Cell cycle is arrested at metaphase by colchicines.

(3) Anaphase:

It is the phase of shortest duration. APC (anaphase promoting complex) develops. Protein binding the two chromatids in the region of centromere is degenerated. So, centromere of each chromosome divides and each chromosome converted into two daughter chromatids. These remains attached to spindle pole of its side by independent chromosomal fiber at kinetochore. Due to shortening of chromosome fibers, chromatid (future chromosomes) move towards the spindle pole with the centromeres projecting towards poles and limbs trailing behind (towards equator). Movement of each chromosome requires 30 ATP. The two pole-ward moving chromosomes of each type remain attached to each other by interzonal fibers. Ultimately, two groups of chromosomes reach at the spindle poles.



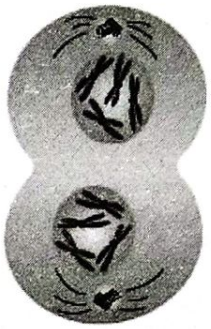
Early anaphase



Late anaphase

(4) Telophase (Reverse of prophase):

Telophase is a reversal of prophase and prometaphase events.The chromatids reach the poles of the cell, uncoil and lengthen to form chromatin again. Spindle fibers disintegrate and the centrioles replicate A nuclear envelope reappears around the chromosomes at each pole and the cell organelles reapears. It is last stage of karyokinesis followed by cytokinesis.



Telophase

5.3. Cytokinesis

It is division of cytoplasm of a cell undergoing karyokinesis to form two daughter cells. It begins in late anaphase and is completed simultaneously with completion of telophase. Non-occurrence of cytokinesis produces multinucleate coenocyte or syncytium. Cytokinesis is of two types, Animal cytokinesis and Plant cytokinesis.

(1) Animal cytokinesis-It takes place by furrow formation by centripetal method called cleavage. Microfilament helps and dense cytoplasm accumulates at metaphasic plate called mid body.

(2) Plant cytokinesis: It is of two types

- **Cleavage cytokinesis:** It takes place by furrow formation by centripetal method called cleavage. Cell membrane forms centripetal furrow or cleavage develops in the middle. Furrow deepens and divides the parent protoplast into two uninucleate protoplast or cells. It occurs in some lower plants, where wall material is deposited in-furrow between daughter cells.
- **Cell plate cytokinesis.** Occurs in higher plants. Remaining spindle joins with microtubules to form phragmoplast (precursor of cell plate). Cell plate is precursor of middle lamella. Golgi body having pectin and other materials appear in middle of phragmoplast. They fuse to form a cell plate. It divides parent binucleate cell into two daughter cells.

5.4. Significance of Mitosis

(1) It is essential for formation of new cells required for growth of all multicellular organisms from a single-celled zygote.

(2) It is an equational division through which identical daughter cells are produced having the same amount and type of genetic constitution as that of the parent cell.

(3) Old and worn out cells are regularly replaced and new body cells are formed through mitosis.

(4) Maintenance of surface /volume Ratio and nucleocytoplasmic Ratio.

(5) If mitosis remains unchecked, it may result in uncontrolled growth of cells leading to cancer or tumor.

6. Meiosis

It is reductional division, in which a cell divides into four daughter cells. Each daughter cell has half number of chromosomes as in the parent cell.

6.1. Characteristics

(1) Discovered by Benden in 1887. Term meiosis was given by – Farmer and Moore in 1905.

(2) Meiosis occurs in certain cells and takes place at a particular time. Occurs only once in life cycle of cell. Meiosis takes days to complete instead of hours or minutes needed for mitosis.

(3) Only the cells of sexually reproducing organisms undergo meiosis. Meiocytes are cells undergoing meiosis. Meiosis produces gametes or gametic nuclei in animals, some lower plants, and various protists and fungi.

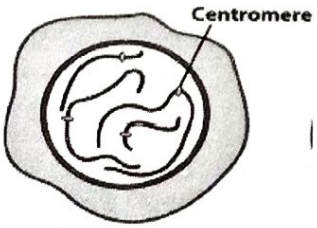
(5) It is studied in anthers of unopened flowers/buds and testis of grasshopper.

(6) It is a double division by which a diploid reproductive cell divides twice to form four haploid cells.

(7) It is also called irregular division because meiosis II may or may not occur.
It has two karyokinesis (meiosis I & meiosis II) and one or two cytokinesis.

6.2. Meiosis I

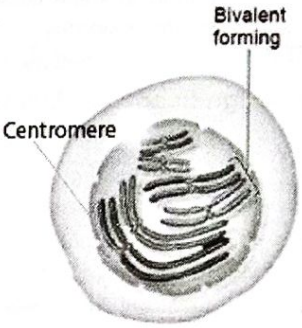
It brings about change from diploid to haploid state.In meiosis I, the two chromatids of a chromosome often become different
due to crossing over, so also called heterotypic division. It is divided into four parts—Prophase I, Metaphase I, Anaphase I, Telophase I.



Leptotene

(1) Prophase I : It has five stages – leptotene, zygotene, pachytene diplotene, and diakinesis

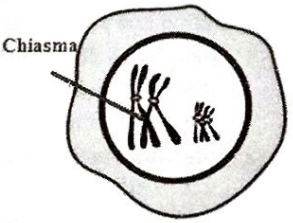
- **Leptotene (leptonema)-**Chromosomes having chromomeres. They are attached to nuclear envelope through an attachment plate. They may form basket-like bouquet stage (diverging from a point lying near centrosome).
- **Zygotene (Zygonema)-** Chromosome are diploid (2n) and there are two chromosomes of each type called homologous chromosomes. Homologous chromosomes paired laterally to form bivalents or zygonema, called synapsis or synthesis. A number of bivalents is half the number of chromosomes. Bivalents are actually tetrads but individual chromatids of two chromosomes are not clear due to presence of SCP between them. Two chromosomes of bivalents are held together by nucleoprotein core (synaptonemal complex protein). This structure is called synaptonemal or synaptonemal complex (Moses). Depending on point of initiation, synapsis can be procentric (starting from centromere), proterminal (pairing beginning from telomere) and intermediate (random pairing starts at several points).



Zygotene

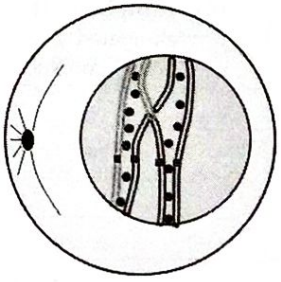
- **Pachytene (Pachynema)-** Each chromosome vertically split into chromatids so bivalent converted into tetrad. Two chromatids of a chromosome are called sister chromatids but the chromatids of homologous chromosome are called non – sister chromatids.

  Recombination nodules (Zickler), having multienzymes (recombinase), appear over bivalents. Breakage and re-union of chromatids segments takes place at these points so it results in exchange of segments between non sisters chromatids of a bivalent is called crossing over. It produces chromosome recombinations (continuous variation), so called first source of continuous genetic variation. Crossing over produces qualitative difference but quantitative difference arise from anaphase.



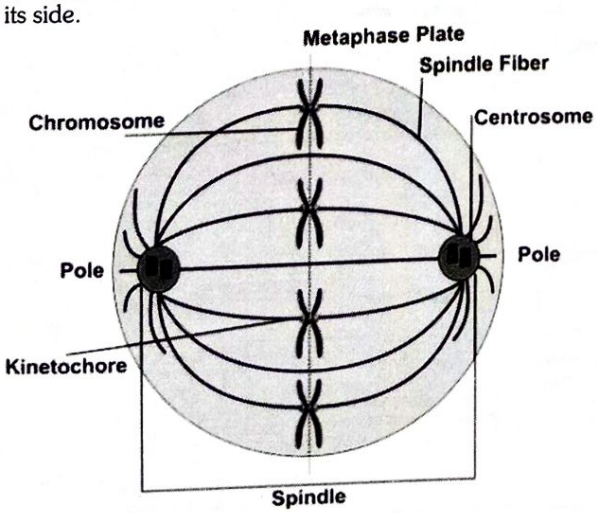
Diplotene

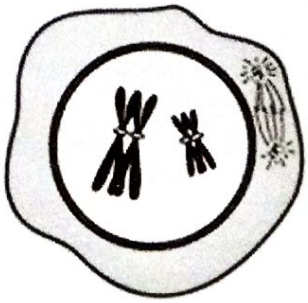
- **Diplotene (Diplotenema)-** Most active phase of prophase. In this phase SCP starts dissolve and chromatids become clear but at some places homologous chromosomes remain attached to each other called chiasmata (X-like structure). Chiasmata are result of crossing over, where SCP persists. (seen by Johannsen). They start moving towards telomere called terminalization. In animal oocytes, diplotene stage is often prolonged.In oocytes of many fishes, amphibians, reptiles and birds, the diplotene chromosomes decondense, elongate and form lampbrush chromosomes.
- **Diakinesis-** Chiasmata shift towards telomere called terminalisation. RNA synthesis stops and Chiasmata disappear completely. Nucleolus degenerates. Nuclear envelope breaks at many places. A spindle begins to develop.



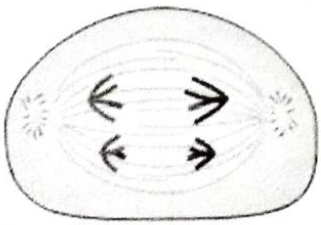
(2) Metaphase I

Congression brings the bivalents/tetrads over the equator of the spindle. On the equator, the chromosome bivalents form double whorl or double metaphasic plate (one paternal and one maternal). During congression chromosome distributed randomly (independent assortment), so called the second source of genetic variation. (No. of possible combination= 2^n, n= No. of homologous pair of chromosome). Chromosome limbs lie over equator while the centromeres are projected outwardly towards the poles. Spindle appears in the area of nucleus. It has asters at the two poles in animal cells (amphiaster) while they are absent in plant cells (anastral). Paired chromosomes get attached to pole by chromosomal spindle fibers. In a pair, each chromosome is attached to only one spindle pole of its side.




Diakinesis

(3) Anaphase I : Homologous chromosomes get separated called disjunction/segregation. which causes reduction of chromosome number to half. It produces genetic variability by independent assortment. The separated chromosomes (dyad/univalent) have two chromatids. They move towards the poles and ultimately form two groups of haploid chromosomes. Quantitative difference arises from this phase.


Anaphase I

(4) Telophase I : Chromosomes elongate and become long and thin. Nucleoplasm and nuclear envelope appear over each chromosome group forming nuclei. Nucleolus is rarely formed.

Interkinesis: It is brief intrameiotic interphase.

Found in some cases in order to synthesize some biochemicals and centriole. No DNA synthesis occurs.

In Trillium telophase I, interkinesis, prophase II are absent so cell enters into metaphase II from anaphase I.

6.3. Significance of Meiosis I

(1) Meiosis I gives, stimulus for formation of gametes or spores.

(2) It reduces the chromosome number to half, performs random separation of paternal and maternal chromosomes, shows gene recombinations due to crossing over

(3) Some time produces chromosome aberration due to non-disjunction.

(4) It introduces variation by forming new gene combinations through crossing over and random assortment of paternal and maternal chromosomes.

6.4. Meiosis II

Homotypic or equational division, which maintains the haploid number converting dyads chromosome state into monad state and separating two chromatids of a chromosome, which have become different due to crossing over.

(1) Prophase II : The chromatin fibers shorten to form chromosomes. Nucleolus and nuclear envelope break down. Spindle is formed in the

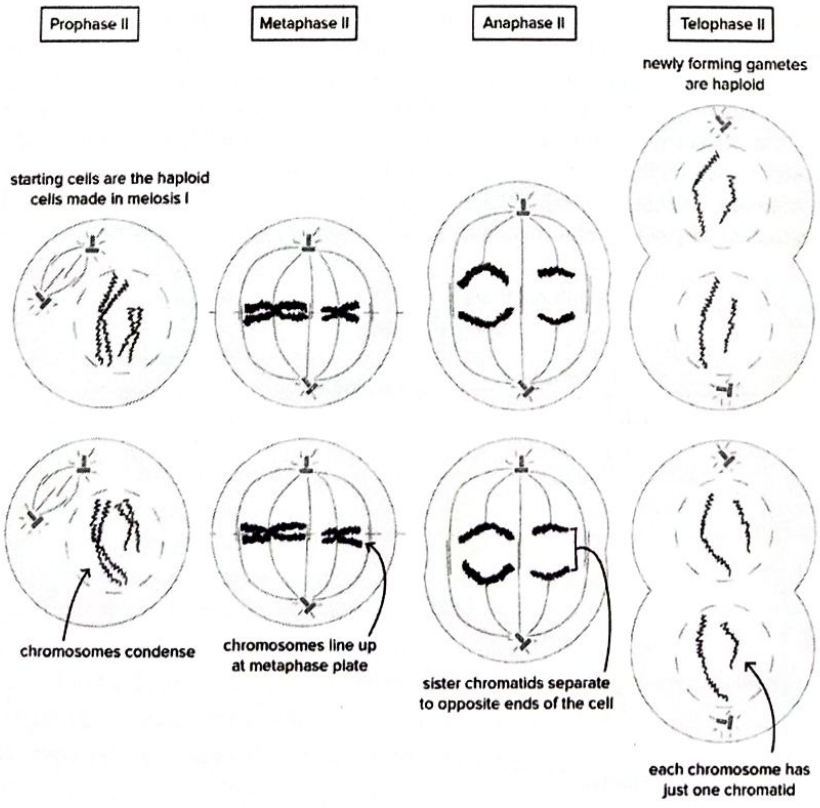
area of each nucleus.

(2) Metaphase II : Telophase I and prophase II are not present in some organisms where anaphase I directly leads to metaphase II, e.g., *Trillium.*

A chromosome comes to lies at the equator of spindle, forming a single metaphase plate. The centromere of each chromosome attaches at both of its surface to spindle poles of their sides with distinct chromosomal spindle fibers.

(3) Anaphase II : Centromere of each chromosome divides into two. This separates the two chromatids of a chromosome into two independent daughter chromosomes. Daughter chromosomes move towards spindle poles forming two groups. Since there were two spindles, total four groups are formed.

(4) Telophase II : The four groups of chromosomes organize themselves into four haploid nuclei. Chromosomes decondense and elongated to return to interphase condition. Nuclear envelope is formed from remains of old nuclear envelope and endoplasmic reticulum. Nucleolus develops from NOR of certain chromosomes.



6.5. Cytokinesis

Cytokinesis may occur after each division (successive type) or simultaneously (after both meiosis). It is generally through cleavage. It forms four haploid cells.

6.6. Importance of Meiosis

(1) **Variations:** Meiosis produces many variations due to independent assortment of chromosomes, crossing over, nondisjunction.

(2) **Maintenance** of chromosome number generation after generation.

(3) **Sexual Reproduction:** Produces gametes, therefore, essential for sexual reproduction

6.7. Types of meiosis

(1) **Gametic/ Terminal:** In many protozoans, all animals and some lower plants, meiosis takes place before fertilization during the formation of gametes, such meiosis is called gametic or terminal meiosis.

(2) **Sporic/Intermediate:** Occurs at the time of microspore and megaspore formation, e.g., Higher plants (bryophytes, pteridophytes **al:** Occurring at the time of gamete formation, e.g. animal.

(3) **Zygotic/Initial:** Occurs at the time of zygote germination, e.g., Thalophyta (algae, fungi), gymnosperms and angiosperms).

Differences between Mitosis and Meiosis

S.N.	Differences	Mitosis	Meiosis
1	**Type of Reproduction**	Asexual	Sexual
2	**Genetically**	Similar	Different
3	**Crossing Over**	No, crossing over cannot occur.	Yes, the mixing of chromosomes can occur.
4	**Number of Divisions**	One	Two
5	**Pairing of Homologs**	No	Yes
6	**Mother Cells**	Can be either haploid or diploid	Always diploid
7	**Number of Daughter Cells produced**	2 diploid cells	4 haploid cells
8	**Chromosome Number**	Remains the same.	Reduced by half.
9	**Chromosomes Pairing**	Does Not Occur	Takes place during zygotene of prophase I and continue to metaphase I.
10	**Creates**	Makes everything other than sex cells.	Sex cells only: female egg cells or male sperm cells.
11	**Takes Place in**	Somatic Cells	Germ Cells
12	**Chiasmata**	Absent	Observed during prophase I and metaphase I.
13	**Spindle Fibres**	Disappear completely in telophase.	Do not disappear completely in telophase I.
14	**Nucleoli**	Reappear at telophase	Do not reappear at telophase I.
15	**Steps**	Prophase, Metaphase, Anaphase, Telophase.	(Meiosis 1) Prophase I, Metaphase I, Anaphase I, Telophase I; (Meiosis 2) Prophase II, Metaphase II, Anaphase II and Telophase II.
16	**Karyokinesis**	Occurs in Interphase.	Occurs in Interphase I.
17	**Cytokinesis**	Occurs in Telophase.	Occurs in Telophase I and in Telophase II.
18	**Centromeres Split**	The centromeres split during anaphase.	The centromeres do not separate during anaphase I, but during anaphase II.
19	**Prophase**	Simple	Complicated
20	**Prophase**	Duration of prophase is short, usually of few hours.	Prophase is comparatively longer and may take days.
21	**Synapsis**	No Synapsis	Synapsis of Homologous chromosomes takes place during prophase.
22	**Exchange of Segments**	Two chromatids of a chromosome do not exchange segments during prophase.	Chromatids of two homologous chromosome exchange segments during crossing over.
23	**Discovered by**	Walther Flemming	Oscar Hertwig
24	**Function**	Cellular reproduction and general growth and repair of the body.	Genetic diversity through sexual reproduction.
25	**Function**	Takes part in healing and repair.	Takes part in the formation of gametes and maintenance of chromosome number.

10. Cell Cycle and Cell Division – Multiple Choice Questions

1. Cell division

1. Which of the following stage is affected by Colchicine
(a) Metaphase (b) Prophase
(c) Interphase (d) Anaphase

2. Condensation of chromosomes occurs in
(a) Prophase I (b) Prophase II
(c) Anaphase (d) Metaphase

3. Which stage connecting link between Meiosis I and Meiosis II
(a) Interphase I (b) Interphase II
(c) Interkinesis (d) Anaphase I

4. The term "meiosis" was coined by
(a) Hertwig and Van Bevin
(b) Sutton and Boveri
(c) Hofmeister and Waldeyer
(d) Farmer and Moore

5. "G_0" state of cells in eukaryotic cell cycle denotes
(a) Checkpoint before entering the next phase
(b) Pausing in the middle of a cycle to cope with a temporary delay
(c) Death of a cell
(d) The exit of cells from cell cycle

6. Spindle apparatus is formed during which stage of mitosis
(a) Prophase (b) Metaphase
(c) Anaphase (d) Telophase

7. Synaptonemal complex was discovered in
(a) 1956 (b) 1950
(c) 1935 (d) 1980

8. A stage in mitosis that starts towards the middle of anaphase and is completed with the telophase is

Or

Division of the cytoplasm after completion of nuclear division is called
(a) Cytokinesis (b) Karyokinesis
(c) Crossing over (d) Interkinesis

9. Which cell division is found during cleavage
(a) Amitosis (b) Mitosis
(c) Closed mitosis (d) Meiosis

10. The term synaptonemal complex refers to the site of
(a) Chromatid separation
(b) Spindle attachment
(c) Replication
(d) Chromosome alignment and recombination

11. At what phase of meiosis are there two cells, each with sister chromatids aligned at the spindle equator
(a) Anaphase II (b) Metaphase II
(c) Metaphase I (d) Anaphase I

12. In meiosis, the daughter cells are not similar to that of a parent because of
(a) Crossing over (b) Synapsis
(c) Both (a) and (b) (d) None of these

13. In which phase of mitosis the chromosomes are arranged around the equator of the spindle
(a) Prophase (b) Metaphase
(c) Anaphase (d) Telophase

14. Yeast cell can progress through the cell cycle in about
(a) 30 minutes (b) 60 minutes
(c) 90 minutes (d) 120 minutes

15. Chromosome number is halved in meiosis during
(a) Metaphase-I (b) Anaphase-I
(c) Metaphase-II (d) Telophase-I

16. Terminalisation occurs in which stage
(a) Pachytene (b) Diplotene
(c) Zygotene (d) Diakinesis

17. During the G_1 phase of cell division
(a) RNA and proteins are synthesized
(b) DNA and proteins are synthesized
(c) Cell prepares for M-phase
(d) Cell undergoes duplication

18. Meiosis and mitosis differ from each other because in meiosis
(a) The four nuclei formed are not similar to parental ones
(b) The homologous chromosomes pair are exchanging Parts
(c) Number of chromosomes gets halved
(d) All the above

19. Prophase of reduction division is divided into a number of stages. The correct chronological sequence is
(a) Leptotene — pachytene — zygotene — diplotene — Diakinesis
(b) Leptotene — diplotene — pachytene — zygotene — Diakinesis
(c) Leptotene — zygotene — diplotene — pachytene — Diakinesis
(d) Leptotene — zygotene — pachytene — diplotene — Diakinesis

20. If we ignore the effect of crossing over, how many different haploid cells arise by meiosis in a diploid cell having $2n=12$
(a) 8 (b) 16
(c) 32 (d) 64

21. G_2 phase of mitosis takes
(a) 50% time of cell cycle
(b) 25 to 33% time of cell cycle
(c) 12 to 16% time of cell cycle
(d) 4% time of cell cycle

22. Prophase is longer in
(a) Mitosis (b) Meiosis
(c) Equal in both (d) Amitosis

23. Chromosome replicate in which stage of meiosis
(a) Prophase I (b) Prophase II
(c) Telophase I (d) Interphase

24. The microtubules from opposite poles of the spindle get attached to the kinetochores of sister chromatids in
(a) Prophase II (b) Metaphase II
(c) Anaphase II (d) None of these

25. Which of the following structure will not be common to the mitotic cell of a higher plant
(a) Cell plate (b) Centromere
(c) Centriole (d) Spindle fibre

26. During mitosis chromosomes go to their poles in a stage called
(a) Prophase (b) Metaphase
(c) Anaphase (d) Telophase

27. G_1, G_2 and S phases are seen in which phase of cell cycle
(a) Metaphase (b) Prophase
(c) Anaphase (d) Interphase

28. During the meiotic division the
(a) Homologous chromosomes are separated
(b) The linkage is disturbed
(c) The homologous chromosomes get paired
(d) All of the above

29. Cell plate is referred as
(a) Germplasm (b) Idioblast
(c) Phragmoplast (d) Middle lamella

30. In meiosis *I*, a bivalent is an association of
(a) Four chromatids and four centromeres
(b) Two chromatids and two centromeres
(c) Two chromatids and one centromere
(d) Two chromatids and four centromeres
(e) Four chromatids and two centromeres

31. The points at which crossing over has taken place between homologous chromosomes are called

Or

The visible expression of the genetic phenomenon of crossing over is called
(a) Protein axis (b) Synaptonemal complexes
(c) Chiasmata (d) Centromeres

32. In which of the following stage, the chromosome is thin and like a long thread
(a) Leptotene (b) Zygotene
(c) Pachytene (d) Diakinesis

33. Meiosis occurs in organisms during
(a) Sexual reproduction
(b) Vegetative reproduction
(c) Both sexual and vegetative reproduction
(d) None of the above

34. Meiosis results in
(a) Production of gametes
(b) Reduction in the number of chromosomes
(c) Introduction of variation
(d) All of the above

35. At which stage of meiosis does the genetic constitution of gametes is finally decided
(a) Metaphase I (b) Anaphase II
(c) Metaphase II (d) Anaphase I

36. Mitosis is characterized by
(a) Reduction division
(b) Equal division
(c) Both reduction and equal division
(d) None of the above

37. Cells which are not dividing are likely to be at
(a) G 1 (b) G 2
(c) G 0 (d) *S* phase

38. Which of the events listed below is not observed during mitosis
(a) Chromatin condensation
(b) Movement of centrioles to opposite poles
(c) The appearance of chromosomes with two chromatids joined together at the centromere
(d) Crossing over

39. A bivalent of meiosis I consist of
(a) Two chromatids and one centromere
(b) Two chromatids and two centromere
(c) Four chromatids and two centromere
(d) Four chromatids and four centromere

40. Identify the wrong statement about meiosis
(a) The pairing of homologous chromosomes
(b) Four haploid cells are formed
(c) At the end of meiosis, the number of chromosomes is reduced to half
(d) Two-cycle of DNA replication occurs

41. Select the correct statement about G 1 phase
(a) The cell is metabolically inactive
(b) DNA in the cell does not replicate
(c) It is not a phase of synthesis of macromolecules
(d) Cell stops growing

42. Chromosome start separating at which stage of mitosis
(a) Early metaphase (b) Late metaphase
(c) Early anaphase (d) Early telophase

43. The role of meiosis
(a) Formation of gametes (b) Bringing haplophase
(c) Bringing diplophase (d) completing the life cycle

44. In pachytene stage of meiosis, the chromosomes appear
(a) Single-stranded (b) Double-stranded
(c) Three stranded (d) Four stranded

45. How many ATP are required during anaphase to move chromosomes from the equator to the poles
(a) 38 ATP (b) 5 ATP
(c) 30 ATP (d) 76 ATP

46. Study the following lists

List-I		List-II	
(A)	Initiation of spindle fibers	(I)	Anaphase-I
(B)	Synthesis of RNA and protein	(II)	Zygotene
(C)	Action of endonuclease	(III)	G_1 phase
(D)	Movement of chromatids towards opposite poles	(IV)	Pachytene
		(V)	late prophase

The correct match is

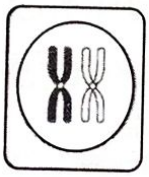
	A	B	C	D
(a)	II	III	IV	V
(b)	III	II	I	V
(c)	V	III	IV	I
(d)	V	III	I	II

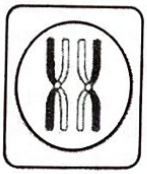
47. Root cells of wheat have $2n = 42$ chromosomes. Which one of the following is the basic chromosome number of wheat
(a) 42 (b) 21
(c) 7 (d) 14

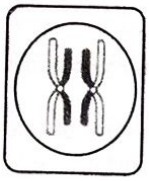
48. In eukaryotic cell cycle, cell fusion experiments show that
(a) When an S-phase cell is fused with a G_1-phase cell, G_1-phase cell is stimulated to synthesize DNA
(b) When an S-phase cell is fused with a G_2-phase cell, DNA synthesis is induced in G_2-phase cell.
(c) When a G_1-phase cell is fused with a G_2-phase cell, DNA synthesis is induced in both G_1 and G_2 phase cells
(d) When a G_1-phase cell is fused with an M-phase cell both G_1 and *M* phase cells are stimulated to synthesize DNA

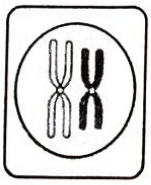
49. How many meiotic division would be required to produce 101 female gametophytes in an angiosperm
(a) 101 (b) 26
(c) 127 (d) None of these

50. Which figure correctly represents a pair of homologous chromosomes at the start of meiosis

(a) 

(b) 

(c) 

(d) 

51. The given figure shows a cell undergoing in Prophase I

Keeping the diagram in view which of the following diagram is correct for one of the cells at the end of meiosis

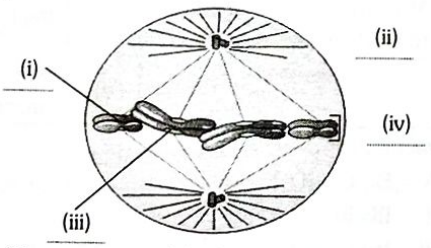
(a) 

(b) 

(c) 

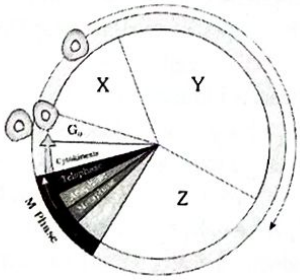
(d) 

52. See the following figure and identify marked lines (i), (ii), (iii) and (iv)



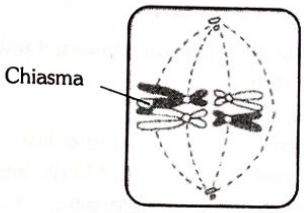
(a) (i) Chromosome, (ii) Centromere, (iii) Centriole, (iv) Chromatid
(b) (i) Chromatid, (ii) Centromere, (iii) Centriole, (iv) Chromosome
(c) (i) Chromosome, (ii) Centriole, (iii) Centromere, (iv) Chromatid
(d) (i) Chromatid, (ii) Centriole, (iii) Centromere, (iv) Chromosome

53. The given diagram is of a typical cell cycle



Identify the parts labeled as X, Y and Z
(a) X - G_1; Y - G_2; Z - G_0 (b) X - G_0; Y - S; Z - G_2
(c) X - G_2; Y - S; Z - G_1 (d) X - G_1; Y - S; Z - G_2

54. The given diagram of a cell undergoing meiosis indicated that crossing over occurs only at the chiasmata



Which of the following gametes will NOT be formed from this cell

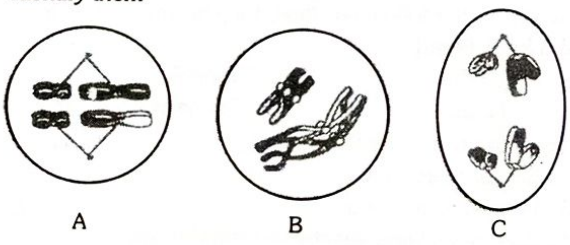
(a) 

(b) 

(c) 

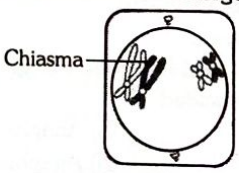
(d) 

55. The given figure represents various stages of cell division. Identify them

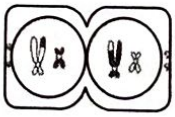


(a) A - Metaphase I, B - Prophase, C - Anaphase
(b) A - Metaphase I, B - Prophase I, C - Anaphase I
(c) A - Metaphase, B - Prophase I, C - Anaphase I
(d) A - Metaphase, B - Prophase I, C - Anaphase

56. The given diagram shows a cell undergoing meiosis



Which diagram shows the next stage in the process

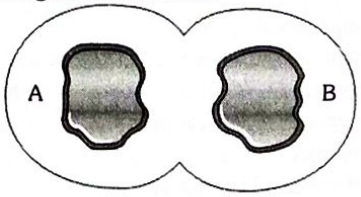
(a) 

(b) 

(c) 

(d) 

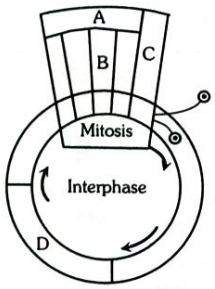
57. The given diagram shows a cell



Which of the following statements related to the image is not correct
(a) The nuclear envelope is disappearing
(b) The cell furrow is forming
(c) It is an animal cell
(d) It is in telophase

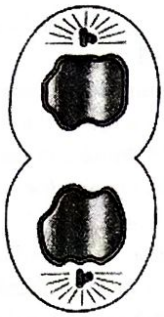
2. NEET

1. Synaptonemal complex is formed during [2001]
   (a) Meiosis (b) Amitosis
   (c) Mitosis (d) Cytokinesis
2. Mitosis is the process by which eukaryotic cells [2000]
   (a) Expose the genes for protein synthesis
   (b) Become specialized in structure and function
   (c) Multiply
   (d) Grow
3. Identify the meiotic stage in which the homologous chromosomes separate while the sister chromatids remain associated at their centromeres [2012]
   (a) Metaphase I (b) Metaphase II
   (c) Anaphase I (d) Anaphase II
4. During gamete formation, the enzyme recombinase participates during [2012; 2014]
   (a) Metaphase - I (b) Anaphase - II
   (c) Prophase – I (Pachytene) (d) Prophase – II
5. Cell division is initiated by [1993]
   (a) Centrosome (b) Centriole
   (c) Centromere (d) Chromomere
6. DNA and histone proteins are synthesized during the following phase of the cell cycle [2005]
   (a) S phase (b) G_2 phase
   (c) G_1 phase (d) None of these
7. The homologous chromosomes follow the process of synapsis in the stage or Pairing of homologous chromosome takes place in [2013]
   (a) Leptotene (b) Zygotene
   (c) Diplotene (d) Pachytene
8. The process of mitosis can be studied in [2002]
   (a) Onion root tip (b) Garlic root tip
   (c) Tendril tip (d) All of the above
9. What is not seen during mitosis in somatic cells [2016]
   (a) Spindle fibers
   (b) Chromosome movement
   (c) Disappearance of nucleolus
   (d) Synapsis
10. The non-sister chromatids twist around and exchange segments with each other during [2016]
    (a) Diplotene (b) Diakinesis
    (c) Leptotene (d) Pachytene
    (e) Zygotene
11. DNA replication takes place in
    Or
    DNA molecule of each chromosome become double in [1996, 2001; 2006]
    (a) G1 Phase (b) G2 Phase
    (c) S phase (d) Mitotic Phase
12. During mitosis ER and nucleolus begin to disappear at [2010]
    (a) Early prophase (b) Late prophase
    (c) Early metaphase (d) Late metaphase
13. Exchange of chromosome segments between maternal and paternal chromatids during meiosis is called [2000]
    (a) Linkage (b) Dominance
    (c) Crossing over (d) DNA multiplication
14. At metaphase, chromosomes are attached to the spindle fibers by their [2011; 2013]
    (a) Kinetochores (b) Centromere
    (c) Satellites (d) Secondary constrictions
15. In 'S' phase of the cell cycle [2014]
    (a) Chromosome number is increased
    (b) Amount of DNA is reduced to half in each cell
    (c) Amount of DNA doubles in each cell
    (d) Amount of DNA remains the same in each cell
16. In the somatic cell cycle [2004]
    (a) A short interphase is followed by a long mitotic phase
    (b) G_2 phase follows meiotic phase
    (c) In G_1 phase DNA content is double the amount of DNA present in the original cell
    (d) DNA replication takes place in S-phase
17. Meiosis takes place in [2013]
    (a) Megaspore (b) Meiocyte
    (c) Conidia (d) Gemmule
18. The complex formed by a pair of synapsed homologous chromosomes is called [2013]
    (a) Axoneme (b) Equatorial plate
    (c) Kinetochore (d) Bivalent
19. Given below is a schematic break-up of the phases/stages of the cell cycle
    Which one of the following is the correct indication of the stage/phase in the cell cycle



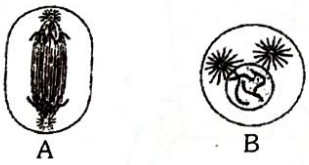
    [2009]
    (a) B-Metaphase (b) C-Karyokinesis
    (c) D-Synthetic phase (d) A-Cytokinesis
20. The best stage to count the number of chromosomes during mitosis is or structure of chromosomes can be best seen at [2004]
    (a) Prophase (b) Metaphase
    (c) Anaphase (d) Telophase
21. Arrange the following events of meiosis in the correct sequence [2015]
    A. Crossing over
    B. Synapsis
    C. Terminalisation of chiasmata
    D. Disappearance of nucleolus
    (a) B, A, C, D (b) A, B, C, D
    (c) B, C, D, A (d) B, A, D, C
22. The number of chromatids in a chromosome at anaphase is [1992]
    (a) 2 in mitosis and 1 in meiosis
    (b) 1 in mitosis and 2 in meiosis
    (c) 2 each in mitosis and meiosis
    (d) 2 in mitosis and 4 in meiosis

23. A stage in cell division is shown in the figure. Select the answer which gives correct identification of the stage with its characteristics **[2013]**



(a)	Telophase	Endoplasmic reticulum and nucleolus not reformed yet
(b)	Telophase	Nuclear envelop reforms, Golgi complex reforms
(c)	Late anaphase	Chromosomes move away from the equatorial plate, Golgi complex not present
(d)	Cytokinesis	Cell plate formed, mitochondria distributed between two daughter cells

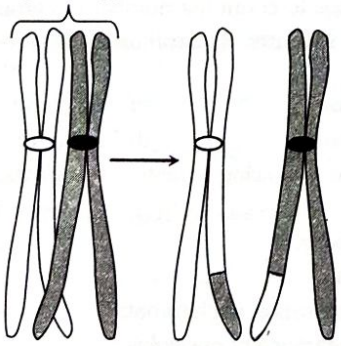
24. Which stages of cell division do the following figures A and B represent respectively **[2010]**



A B

(a) Prophase – Anaphase
(b) Metaphase – Telophase
(c) Telophase – Metaphase
(d) Late Anaphase – Prophase

25. Given below is the representation of a certain event at a particular stage of a type of cell division. Which is this stage



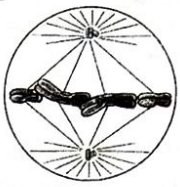
[2012]

(a) Prophase I during meiosis
(b) Prophase II during meiosis
(c) Prophase of Mitosis
(d) Both prophase and metaphase of mitosis

26. How many mitotic divisions are needed for a single cell to make 128 cells **[1997]**

(a) 7 (b) 14
(c) 28 (d) 32

27. Select the correct option with respect to mitosis



[2011; 2013]

(a) chromosome attach to the spindle fiber and arranged at equitorial plate
(b) Chromatids separate but remain in the center of the cell in anaphase
(c) Chromatids start moving towards opposite poles in telophase
(d) Golgi complex and endoplasmic reticulum are still visible at the end of prophase

28. During which phase(s) of cell cycle amount of DNA in a cell remains at the 4C level if the initial amount is denoted as 2C **[2014]**

(a) Only G_2 (b) G_2 and M
(c) G_0 and G_1 (d) G_1 and S

29. Select correct option

	Column I		Column II
(A)	Synapsis aligns homologous chromosomes	(i)	pachytene
(B)	Synthesis of RNA and protein	(ii)	Zygotene
(C)	Action of enzyme recombinase	(iii)	G_2-phase
(D)	Centromeres do not separate but chromatids move towards opposite poles	(iv)	Anaphase-I

[2015]

	(A)	(B)	(C)	(D)
(a)	(ii)	(iii)	(i)	(iv)
(b)	(i)	(ii)	(iii)	(iv)
(c)	(ii)	(iii)	(iv)	(i)
(d)	(ii)	(i)	(iii)	(iv)

30. A somatic cell that has just completed the S-phase of its cell cycle, as compared to gamete of the same species, has **[2015]**

(a) Same number of chromosomes but twice the amount of DNA
(b) Twice the number of chromosomes and four times the amount of DNA
(c) Four-time the number of chromosomes and twice the amount of DNA
(d) Twice the number of chromosomes and twice the amount of DNA

31. Select the incorrect match **[2018]**

(a)	Polytene chromosomes	–	Oocytes of amphibians
(b)	Submetacentric chromosomes	–	L-shaped chromosomes
(c)	Allosomes	–	Sex chromosomes
(d)	Lampbrush chromosomes	–	Diplotene bivalents

32. The stage during which separation of the paired homologous chromosomes begins is **[2018]**

(a) Zygotene (b) Diakinesis
(c) Diplotene (d) Pachytene

3. AIIMS

1. Microtubule depolymerizing drug such as colchicine is expected to **[2012]**
   (a) Inhibit spindle formation during mitosis
   (b) Inhibit cytokinesis
   (c) Allow mitosis beyond metaphase
   (d) Induce formation of multiple contractile rings
2. Which of the following statements is incorrect about G_0 phase **[2012]**
   (a) Mitosis occurs after G_0 phase
   (b) Biocatalysts can be used to exit the G_0 phase
   (c) Cell volume keeps on increasing during this Phase
   (d) Cell metabolism occurs continuously in G_0 Phase
3. Regarding the sequence of the cell cycle, which one is correct **[1999]**
   (a) G_1, G_2, S and M (b) S, G_1, G_2, and M
   (c) G_1, S, G_2, and M (d) G_2, S, G_1, and M
4. Calcium dependent kinases can control **[2010]**
   (a) Cell cycle activities (b) DNA replication
   (c) Cell surface receptors (d) Membrane structure
5. In which stage of cell division chromosomes are most condensed **[2010]**
   (a) Prophase (b) Metaphase
   (c) Anaphase (d) Telophase
6. Which is not characteristic of meiosis **[2011]**
   (a) Two stages of DNA replication, first before meiosis I and second before meiosis II
   (b) Recombination and crossing over
   (c) Sister chromatids separate during anaphase II
   (d) Nuclear membrane disappears towards the end of Prophase
7. The protein for spindle fibre is **[2001]**
   (a) Myosin (b) Actin
   (c) Tubulin (d) Myoglobin
8. Which one of the following precedes re-formation of the nuclear envelope during M phase of the cell cycle **[2008]**
   (a) Formation of the contractile ring, and formation of the phragmoplast
   (b) Formation of the contractile ring, and transcription from chromosomes
   (c) Decondensation of chromosomes, and reassembly of the nuclear lamina
   (d) Transcription from chromosomes, and assembly of the nuclear lamina
9. Beads on a string like structures of **A** are seen in **B,** which further condense to form chromosomes in **C** stage of cell division. What are **A, B** and **C** **[2012]**

	A	B	C
(a)	Chromonema	Chromatin	Metaphase
(b)	Chromatin	Chromatid	Metaphase
(c)	Chromonema	Chromosome	Anaphase
(d)	Chromonema	Chromatid	Anaphase

10. What is the correct sequence of the steps given here? Also, work out the process depicted in the steps **[2009]**
    i. Homologous chromosomes move toward opposite poles of the cell; chromatids do not separate
    ii. Chromosomes gather together at the two poles of the cell and the nuclear membranes reform
    iii. Homologous chromosomes pair and exchange segments
    iv. Homologous chromosomes align on a central plate
    v. The haploid cells separate completely
    (a) The correct sequence is III → IV → I → II → V and the process is meiosis-I
    (b) The correct sequence is II → I → V → IV → III and the process is mitosis
    (c) The correct sequence is IV → I → III → II → V and the process is meiosis-I
    (d) The correct sequence is II → V → IV → I → II and the process is mitosis

4. Assertion & Reason

Read the assertion and reason carefully to mark the correct option out of the options given below:

(a) If both the assertion and the reason are true and the reason is a correct explanation of the assertion
(b) If both the assertion and reason are true but the reason is not a correct explanation of the assertion
(c) If the assertion is true but the reason is false
(d) If both the assertion and reason are false
(e) If the assertion is false but reason is true

1. Assertion : Reduction division occurs in anaphase-I. So there is no need for meiosis.
   Reason : Meiosis-II occurs to separate homologous chromosomes.
2. Assertion : Meiotic division results in the production of haploid cells.
   Reason : Synapsis occurs during zygotene of meiosis.
3. Assertion : Synthesis of DNA takes place in the S-phase of interphase.
   Reason : Every chromosome, during metaphase, has two chromatids.
4. Assertion : Meiosis takes place in pollen mother cells.
   Reason : Each pollen mother cell produces 4 haploid pollen grains.