Answers to Questions for Comprehension

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Q1. There is a limit to how large a cell can grow because, as a cell grows, the volume of its cytoplasm increases at a faster rate than the surface area of its plasma membrane. As the volume of the cytoplasm increases, more materials must pass through this membrane. If a cell continues to grow in size, its plasma membrane would eventually be too small to meet its metabolic needs. Thus, a cell must stop growing once it reaches a certain size. New growth must, therefore, come from the addition of new cells.

Q2. The cell cycle is the continuous sequence of growth and division that a cell goes through during its lifetime. By convention, a single cell cycle is defined as the sequence of events from one cell division to the next.

Q3. The following is a summary of the technological advances that lead to the development of new theories about the origin of cells:

- Until the mid-1800s, most scientists accepted the theory of spontaneous generation.
- 1840s: Advances in lens technologies increased the magnification power of microscopes from 270× to 1200×. This advance helped scientists observe cell division and propose an alternative theory of how living cells originate.
- 1855: Virchow became the first scientist to publish the conclusion that new cells arise only from the division of other cells.
- 1879: Flemming used synthetic clothing dye (first produced in the mid-1800s) to stain a specimen of tissue. The stain was picked up by a substance in the nucleus that he called chromatin. Within a few years, Flemming offered the first accurate description of the cell cycle and the process of cell division in animal and plant cells.

Q4. The central feature of the cell cycle is the way that genetic material is duplicated and then passed from the original cell (parent cell) to the new cell (daughter cell).

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Q5. The genetic information of a cell is contained in the DNA of its chromosomes. A chromosome is a length of DNA and its associated proteins. In eukaryotic cells, the chromosomes are found in the nucleus.

Q6. A centromere is a specialized, constricted (pinched-in) region that is found in the centre of a chromosome. It joins pairs of identical chromosomes (chromatids) in a chromosome pair.

Q7. There are 46 chromosomes in the somatic cells of humans.

Q8. Homologous chromosomes carry the same genes—areas of DNA that contain specific genetic information—at the same location; however, they are not identical. Instead they carry different forms (alleles) of the same gene. Homologous chromosomes also have several other characteristics in common, such as their length, centromere location, and banding pattern.

Q9. The X and Y chromosomes are known as the sex chromosomes because they determine the sex of the individual. A human female has two X chromosomes, and a human male has one X chromosome and one Y chromosome.

Q10. A cell that contains pairs of homologous chromosomes is said to be diploid, a cell that contains unpaired chromosomes is said to be haploid, and a cell that contains sets of more than two homologous chromosomes is polyploid.

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Q11. The particular set of chromosomes that an individual possesses is called the individual's karyotype.

Q12. A pair of homologous chromosomes carries the same genes at the same locations (loci) on each chromosome. Each pair of the 22 human chromosomes, and the X and Y chromosome, is distinct from the others because it carries different genes.

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Q13. The cell cycle is made up of two main stages: a growth stage (interphase) and a division stage (cell and cytoplasmic division). Interphase includes a series of distinct phases: G1 (Gap 1 or Growth 1), S (synthesis), and G2 (Gap 2 or Growth 2). The division stage consists of mitosis and cytokinesis.

Q14. G1 phase: Rapid growth and metabolic activity occurs.

S phase: The DNA in the chromatin replicates to create a second identical set of DNA.

G2 phase: The cell rebuilds its reserves of energy to prepare for division. As well, the cell manufactures proteins and other molecules to make structures required for division of the nucleus and cell.

Mitosis: The genetic material and the contents of the nucleus are divided into two complete and separate sets.

Cytokinesis: The cytoplasm and the organelles are divided into two separate cells.

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Q15. The processes of mitosis and cytokinesis have three important functions:

- Growth: They enable organisms to grow from a single-celled zygote into a mature organism that may contain hundreds of trillions of cells.
- Maintenance: They produce new cells to replace worn or dead cells.
- Repair: They can regenerate damaged tissues.

Q16. It is important for each daughter cell to receive the correct genetic information; otherwise it might not be able to carry out its specific function. In the absence of precise, exact genetic duplication, one of the daughter cells will receive a flawed, mutant genome that may threaten its ability to survive, or even worse, cause it to grow uncontrollably as a cancer cell.

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Q17. The four phases of mitosis are prophase, metaphase, anaphase, and telophase.

Q18. The key events that happen to chromosomes in each phase are as follows:

- Prophase—the chromatin condenses into tightly packed chromosomes.
- Metaphase—spindle fibres from opposite poles attach to the centromere of each chromosome; the spindle fibres guide the chromosomes to the equator of the cell.
- Anaphase—each centromere splits apart; the sister chromatids separate and are pulled to opposite poles of the cell as the spindle fibres attached to them shorten.
- Telophase—the chromatids have reached the opposite poles of the cell; the chromatids begin to unwind into the longer and less visible strands of chromatin.

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Q19. The structural differences between plant cells and animal cells lead to some differences in mitosis and cytokinesis:

- Plant cells do not have centrioles, but they do form a spindle apparatus.
- The rigid cell wall of a plant cell is much stronger than the membrane of an animal cell. The cell wall does not furrow and pinch in during cytokinesis. Instead, a membrane called a cell plate forms between the two daughter nuclei. This cell plate extends across the diameter of the cell, and it is then reinforced by the addition of cellulose and proteins to create a new cell wall.

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Q20. The two key outcomes of meiosis are reduction and recombination. Meiosis is sometimes referred to as a reduction division because it is a form of cell division that produces daughter cells with fewer chromosomes than the parent cells. Recombination is a key outcome of meiosis as the products of meiosis have different combinations of genes. This genetic recombination gives rise to offspring that are genetically distinct from one another and their parents.

Q21. Meiosis is a special type of cell division that occurs only in reproductive organs. Meiosis produces genetically unique reproductive cells called gametes. The gametes, either eggs or sperm, are haploid (n), which means that they contain only one copy of each type of chromosome that the diploid (2n) parent cell contains. This differs from the function of mitosis, which creates new, genetically identical diploid cells to enable tissue growth, maintenance, and repair.

Q22. Meiosis occurs only in reproductive organs.

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Q23. Meiosis I begins with prophase I. In prophase I, each pair of homologous chromosomes align side-by-side in a formation called a tetrad. This process is called synapsis. It is during prophase I that crossing over of homologous chromosomes occurs. In the next phase, metaphase I, spindle fibres attach to the centromeres of each chromosome and guide each tetrad to the equator of the cell where the chromosomes line up as homologous pairs. Independent assortment occurs in this phase. During anaphase I, the spindle fibres shorten, causing the homologous chromosomes to separate from one another and move to opposite poles of the cell. Because the sister chromatids are still held together, the centromeres do not split as they do in mitosis. The result is that a single chromosome (made up of two sister chromatids) from each homologous pair moves to each pole of the cell. Next, in telophase I, the homologous chromosomes begin to uncoil and the spindle fibres disappear. The cytoplasm is divided, the nuclear membrane forms around each group of homologous chromosomes, and two cells are formed. (Some cells move directly from anaphase I to meiosis II). The phases of meiosis II are similar to the phases of mitosis; however, each cell that enters meiosis II is haploid, although it consists of replicated chromosomes. Each cell proceeds through prophase II, in which the centrioles move to opposite poles and the nuclear membrane breaks down; metaphase II, in which the chromosomes line up at the equator; anaphase II, in which the centromeres split and the chromatids are pulled to opposite poles; and telophase II, in which the nuclear membrane forms around each separated set of chromosomes. At the end of meiosis II, the four new daughter cells are still haploid, but they contain single unreplicated chromosomes.

Q24. The result of mitosis is two daughter cells with exactly the same number of chromosomes as the parent cell ($2n$). The result of meiosis is four cells with half the number (n) of chromosomes as the parent cell.

Q25. During crossing over, homologous chromosomes synapse during prophase I. While they are lined up side-by-side, non-sister chromatids exchange pieces of chromosome. As a result of crossing over, individual chromosomes contain some genes of maternal origin and some genes of paternal origin. Independent assortment occurs in metaphase I. Chromosomes are arranged in homologous pairs along the equator of the cell. In each pair, the chromosome of maternal origin is oriented toward one pole of the cell while the chromosome of paternal origin is oriented toward the other pole. This orientation of each pair of homologous chromosomes is independent of the orientation of the other pairs. Therefore, some maternal homologues and some paternal homologues face each pole of the cell. This means that the resulting gametes will have different combinations of parental chromosomes.

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26. Sometimes chromosomes or chromatids do not separate as they should during meiosis. This phenomenon is called nondisjunction. Nondisjunction occurs in anaphase I and II of meiosis. In anaphase I, nondisjunction occurs when homologous chromosome pairs do not separate to opposite poles; instead, one entire pair is pulled toward the same pole together. In anaphase II, nondisjunction occurs when sister chromatids do not separate to opposite poles; instead, both sister chromatids are pulled toward the same pole together. As a result, nondisjunction produces gametes that have either too few or too many chromosomes. When one chromosome is lost due to nondisjunction, it is called monosomy. In this case, the gamete is missing one chromosome of a homologous pair. Nondisjunction can also result in trisomy—the gain of an extra chromosome.

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Q27. Key similarities between spermatogenesis and oogenesis are as follows: both processes begin with a diploid germ cell; both result in haploid gametes; both under go meiosis I and II. Key differences include the following: oogenesis occurs in females, while spermatogenesis occurs in males; oogenesis begins before puberty (cells are arrested at prophase I) while spermatogenesis begins at puberty; oogenesis is arrested twice, once at prophase I and once at metaphase II, while spermatogenesis is not;

oogenesis results in the formation of polar bodies due to asymmetrical cytokinesis, while spermatogenesis does not; oogenesis results in one viable gamete, while spermatogenesis results in four.

Q28. The unequal division of cytoplasm means that only one egg cell is produced from the division of the secondary oocyte. This egg cell, however, contains a large quantity of nutrients that the zygote requires prior to implantation, thus helping to ensure the health of the zygote.

Q29. In humans, spermatogenesis continues from puberty until old age. This process differs from oogenesis where, in human females, more than a decade separates the events of meiosis I and II. In oogenesis, the primary oocytes begin meiosis I before birth, but cell division stalls in prophase I. The cells remain in this suspended state until puberty. At puberty, a hormone signal triggers a single primary oocyte to resume meiosis and the primary oocyte completes meiosis I. The secondary oocyte that results only completes a second meiotic division if it comes into contact with a sperm cell and fertilization occurs. The timing of oogenesis and spermatogenesis are specific to their functions as follows: the timing of oogenesis allows female gametes to undergo an extended period of growth, which is necessary to accumulate resources for early embryonic stages of development. Male gametes do not require the extended growth phase and can be produced continually.

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Q30. While most women release only a single secondary oocyte at each ovulation, occasionally more than one secondary oocyte may be released. If both of these oocytes are fertilized and successfully implant in the uterus, fraternal twins may be born. On the other hand, if a single zygote or blastocyst divides into two separate bodies in the first few days of embryonic development, identical twins may be born.

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Q31. Asexual reproduction is a reproductive process in which a parent organism produces genetically identical offspring. Sexual reproduction involves the production of gametes by meiosis, followed by fertilization between genetically distinct parental gametes to produce genetically distinct offspring.

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Q32. Prokaryotes, such as bacteria, have a single, circular chromosome and no nucleus. They reproduce asexually by replicating the DNA and then distributing one complete copy of the DNA into each of two daughter cells. There are no spindle fibres or centrioles, as in eukaryotic cells, that divide the nucleus by mitosis, nor is there a nuclear envelope.

Q33. Conjugation is the transfer of genetic material from one cell to another by cell-to-cell contact through a bridging structure (pilus). This results in a single cell with new genetic material. Neither meiosis, nor gamete formation occurs. In sexual reproduction, haploid gametes that contain half the genetic material of the diploid organism are formed by meiosis. Gametes unite in the process of fertilization and form a new diploid organism that is genetically unique.

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Q34. Plants can reproduce asexually via vegetative reproduction. In this process, a new plant develops at the end of a leaf, stem, or root of the parent plant. Another form of asexual reproduction is called fragmentation. During this process a new plant develops from a fragment (portion) of a parent plant, such as a single leaf, tuber, or a cutting from the parent plant. Both of these methods result in a new plant that is genetically identical to its parent.

Q35. Parthenogenesis is considered to be a form of asexual reproduction because the egg is not fertilized by the male gamete. As such, it is the sole source of genetic material for the creation of an embryo. The resulting offspring is genetically identical to the parent.

Q36. A spore is a structure that contains genetic material and cytoplasm surrounded by a protective sheath or wall. The wall protects the contents until conditions are favourable, at which point the spore wall opens and the organism begins to develop. Because spores tend to be very small, they are readily dispersed in water and by the wind. Spores may be haploid or diploid, and not all spores are the product of asexual reproduction. While some organisms produce spores by mitosis, others produce spores by meiosis.

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Q37. The life cycle of plants consists of a haploid generation and a diploid generation that alternate. This is called the alternation of generations. Strictly speaking, the term “alternation of generations” refers to this alternation of diploid and haploid generations. This reproductive strategy is found only in plants. Some animal life cycles, however, alternate between asexually-reproducing and sexually-reproducing phases in a process called the “alternation of reproductive cycles.”