School Connect Online

# SCO INTERNATIONAL BIOLOGY OLYMPIAD

## CLASS 12 SAMPLE PAPER

**2024-25 Sample | Answer Key & Explanations Included**

### Biology Olympiad document designed for senior secondary learners and global academic review.

- Class 12 Biology paper with structured sections and clear marking policy
- Compact question-number markers with all passage text inside the question block
- Answer key and explanations formatted for teacher, parent, and student use
- Academic layout aligned with SCO International Olympiad publishing standards

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|---|---|---|---|---|
| Biology | Genetics | Biotechnology | Ecology | Health |
| Evolution | Reproduction | Molecular Biology | Case Studies | Achievers |

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# Section A - General Biology and Core Concepts

*Questions 1-30 carry 1 mark each.*

**Q.1** A recent study on parthenogenesis in certain species of whiptail lizards showed that these lizards reproduce asexually when mates are scarce. Which of the following is the most likely evolutionary advantage of parthenogenesis in this scenario?

A. Increased genetic diversity

B. Rapid colonization of new habitats

C. Enhanced resistance to disease

D. Reduced mutation rate

**Answer: B**

**Explanation:**

Parthenogenesis allows reproduction without a mate, enabling rapid population growth and colonization in new or isolated habitats, although it reduces genetic diversity.

**Q.2** Research in pollination ecology found that a rare orchid uses mimicry to attract pollinators by imitating the appearance of female insects. Which mechanism best describes this phenomenon?

A. Production of nectar to reward pollinators

B. Visual mimicry that deceives male insects

C. Emission of odors similar to decaying organic matter

D. Temporal synchronization with pollinator emergence

**Answer: B**

**Explanation:**

This deceptive strategy involves mimicking the visual cues of female insects to attract males, thus ensuring pollination without offering a nectar reward.

**Q.3** A study on assisted reproductive technologies (ART) showed that intracytoplasmic sperm injection (ICSI) significantly improves fertilization in severe male factor infertility. What is the primary mechanism by which ICSI enhances fertilization success?

A. Enhancing sperm motility

B. Bypassing the need for sperm capacitation

C. Directly injecting a single sperm into the egg's cytoplasm

D. Promoting chemical activation of the egg membrane

**Answer: C**

**Explanation:**

ICSI involves injecting a single sperm directly into an egg, overcoming natural barriers to fertilization and significantly improving outcomes in cases with low sperm count or motility.

**Q.4** Recent public health research indicates that long-acting reversible contraceptives (LARCs) dramatically reduce unintended pregnancies. Which LARC method is noted for its high efficacy due to minimal user intervention?

A. Oral contraceptive pills

B. Intrauterine devices (IUDs)

C. Barrier methods

D. Injectable contraceptives

**Answer: B**

**Explanation:**
IUDs are highly effective because once inserted they require little user compliance, thereby minimizing human error and significantly reducing unintended pregnancies.

**Q.5** In a dihybrid cross of pea plants with two traits (seed shape and color), the observed phenotypic ratio is 9:3:3:1. What does this ratio indicate about the inheritance of the two traits?

A. Complete dominance with independent assortment

B. Incomplete dominance with genetic linkage

C. Codominance with epistasis

D. Multiple alleles with segregation distortion

**Answer: A**

**Explanation:**
A 9:3:3:1 ratio is the classical result of a dihybrid cross with complete dominance and independent assortment of two unlinked traits.

**Q.6** CRISPR-Cas9 technology has revolutionized gene editing. In this system, which component is primarily responsible for guiding the Cas9 enzyme to the target DNA sequence?

A. Cas9 protein itself

B. Guide RNA (gRNA)

C. Protospacer adjacent motif (PAM)

D. DNA polymerase

**Answer: B**

**Explanation:**
The guide RNA (gRNA) contains a sequence complementary to the target DNA and directs the Cas9 nuclease to the correct site for editing.

**Q.7** Long-term studies of Darwin's finches in the Galápagos have demonstrated that beak sizes change in response to food availability. Which evolutionary mechanism best explains this rapid phenotypic change?

A. Genetic drift

B. Founder effect

C. Natural selection

D. Gene flow

**Answer: C**

**Explanation:**
Natural selection favors individuals with beak sizes best suited to the available food resources; thus, changes in food supply lead to rapid shifts in beak size distribution over generations.

**Q.8** Recent research on the human gut microbiome has linked microbial composition to mental health. Which mechanism is most likely responsible for this connection?

A. Direct invasion of brain tissue by bacteria

B. Production of neurotransmitter precursors by gut bacteria

C. Horizontal gene transfer altering neuronal DNA

D. Enhanced absorption of dietary lipids affecting brain function

**Answer: B**

**Explanation:**

Certain gut bacteria produce precursors to neurotransmitters (such as serotonin and dopamine), which can influence brain function and mood.

**Q.9** Scientists have used CRISPR technology to create drought-resistant rice varieties. What genetic modification is most likely responsible for increased drought resistance in these plants?

A. Enhanced chlorophyll synthesis

B. Altered root architecture for improved water uptake

C. Increased sugar content in leaves

D. Reduced leaf area to minimize transpiration

**Answer: B**

**Explanation:**

Modifications that enhance root architecture allow plants to explore a larger soil volume, improving water uptake during drought conditions.

**Q.10** A biotechnology research team engineered bacteria capable of degrading PET plastic. Which enzyme, identified in recent studies, is most effective in breaking down PET polymers?

A. Cellulase

B. Laccase

C. PETase

D. Lipase

**Answer: C**

**Explanation:**

PETase is the enzyme that has been discovered to effectively degrade polyethylene terephthalate (PET), making it promising for bioremediation of plastic waste.

**Q.11** In recombinant DNA technology, which vector is most commonly used to introduce foreign genes into bacterial cells for protein production, such as human insulin?

A. Bacteriophage lambda

B. Plasmid

C. Cosmid

D. Artificial chromosome

**Answer: B**

**Explanation:**

Plasmids are small, circular DNA molecules that serve as the most common vectors in bacterial genetic engineering due to their ease of manipulation and replication.

**Q.12** A novel diagnostic test for viral infections uses PCR to amplify viral DNA. Which component of the PCR reaction is essential for synthesizing new DNA strands during the amplification process?

A. RNA polymerase

B. DNA ligase

C. Taq polymerase

D. Restriction enzyme

**Answer: C**

**Explanation:**

Taq polymerase is a thermostable DNA polymerase that synthesizes new DNA strands during PCR, even at high temperatures required for denaturation.

**Q.13** A study on overfishing in a coastal region revealed a sharp decline in the population size of a commercially important fish species. Which principle of population dynamics best explains the reduction in genetic diversity observed in the remaining population?

A. Founder effect

B. Bottleneck effect

C. Competitive exclusion

D. Island biogeography

**Answer: B**

**Explanation:**

A bottleneck effect occurs when a population's size is drastically reduced, leading to a loss of genetic diversity due to a smaller breeding pool.

**Q.14** In a wetland ecosystem, excessive nutrient runoff from agriculture has led to widespread algal blooms. Which process best describes the subsequent decline in dissolved oxygen levels in the water?

A. Eutrophication

B. Biomagnification

C. Parasitism

D. Mutualism

**Answer: A**

**Explanation:**

Eutrophication occurs when excessive nutrients stimulate algal blooms; the decomposition of these algae depletes dissolved oxygen, adversely affecting aquatic life.

**Q.15** A conservation study revealed that the removal of apex predators from an ecosystem resulted in a trophic cascade that reduced biodiversity. Which statement best describes a trophic cascade?

A. Increased primary productivity due to predator removal

B. Direct changes in plant diversity caused solely by herbivore overpopulation

C. Ripple effects that alter the abundance of species at multiple trophic levels

D. A stabilizing effect on ecosystems due to reduced competition

**Answer: C**

**Explanation:**

A trophic cascade refers to the ripple effects throughout the ecosystem that occur when a change at one trophic level (such as the removal of apex predators) leads to significant changes in the abundance and diversity of species at other levels.

**Q.16** Recent studies have detected microplastics even in remote Arctic regions. Which process is most responsible for the long-range distribution of microplastics?

A. Volcanic eruptions

B. Atmospheric transport

C. Ocean currents

D. Animal migration

**Answer: B**

**Explanation:**

Atmospheric transport can carry microplastic particles over vast distances, depositing them in remote regions far from their original source.

**Q.17** A public health study reported a significant decline in teenage pregnancies after the introduction of comprehensive sex education programs. Which factor is most directly responsible for this outcome?

A. Increased use of contraception

B. Reduced peer pressure

C. Increased availability of hormonal treatments

D. Delayed onset of puberty

**Answer: A**

**Explanation:**

Comprehensive sex education improves awareness and leads to higher rates of contraceptive use, directly reducing unintended teenage pregnancies.

**Q.18** Advances in assisted reproductive technologies (ART) have enabled successful pregnancies for couples with infertility issues. Which procedure involves fertilizing an egg outside the human body and then transferring the embryo to the uterus?

A. Gamete intrafallopian transfer (GIFT)

B. In vitro fertilization (IVF)

C. Zygote intrafallopian transfer (ZIFT)

D. Intracytoplasmic sperm injection (ICSI)

**Answer: B**

**Explanation:**

In vitro fertilization (IVF) is the process of fertilizing an egg with sperm in a laboratory setting and subsequently transferring the resulting embryo to the uterus.

**Q.19** Recent genomic research has uncovered multiple instances of horizontal gene transfer between bacteria and eukaryotes. Which of the following best describes how horizontal gene transfer can influence evolution?

A. It increases genetic diversity by introducing new genes across species boundaries.

B. It causes genetic drift by random changes in allele frequencies.

C. It stabilizes genomes by eliminating harmful mutations.

D. It primarily affects non-coding regions of the genome.

**Answer: A**

**Explanation:**

Horizontal gene transfer allows organisms to acquire genes from distantly related species, thereby increasing genetic diversity and potentially conferring new adaptive traits.

**Q.20** Recent advances in epigenetics show that environmental factors can lead to heritable changes in gene expression without altering the underlying DNA sequence. Which mechanism is most directly involved in such epigenetic modifications?

A. DNA mutation

B. Histone modification

C. RNA splicing

D. Chromosomal translocation

**Answer: B**

**Explanation:**

Histone modifications (such as methylation and acetylation) alter chromatin structure and gene accessibility without changing the DNA sequence, making them central to epigenetic regulation.

**Q.21** A research lab using CRISPR–Cas9 to edit a gene in a crop plant reports that 75% of the transformed cells show the desired edit. However, DNA sequencing reveals that 10% of those successfully edited cells also carry off-target mutations in a set of related genes. If a researcher screens 200 transformed cells, how many cells are expected to have the desired mutation without any off-target effects?

**Options:**

A) 120

B) 135

C) 150

D) 165

**Answer: B) 135**

**Explanation:**

First, calculate the number of cells with the desired edit:

200 × 0.75 = 150 cells.

Next, determine how many of these 150 cells also have off-target effects:

150 × 0.10 = 15 cells.

Finally, subtract the off-target cases from the total edited cells:

150 – 15 = 135 cells.

Thus, about 135 cells will have the desired mutation without off-target modifications.

**Q.22** In a genomic study, scientists discovered that a fungus possesses an enzyme-coding gene that is more similar to bacterial genes than to those of other fungi. Which process most likely explains this unusual similarity?

**Options:**

A) Vertical inheritance

B) Convergent evolution

C) Horizontal gene transfer

D) Gene duplication followed by divergence

**Answer: C) Horizontal gene transfer**

**Explanation:**

Horizontal gene transfer (HGT) involves the movement of genetic material between unrelated organisms. The observation that the fungal gene is more similar to bacterial homologs strongly suggests that the gene was acquired from bacteria rather than inherited through the standard vertical (parent-to-offspring) route.

**Q.23** In a study on mice fed a high-fat diet, researchers observed that the offspring showed altered expression of several metabolic genes despite no detectable change in their DNA sequences. Which epigenetic mechanism is most likely responsible for these heritable changes?

**Options:**

A) DNA mutation

B) DNA methylation

C) Chromosomal translocation

D) RNA interference

**Answer: B) DNA methylation**

**Explanation:**

DNA methylation is a key epigenetic modification that can change gene expression without altering the underlying DNA sequence. Environmental factors, such as a high-fat diet, can induce changes in DNA methylation patterns that are sometimes passed to offspring, altering metabolic gene expression.

**Q.24** A population of beetles originally has an allele frequency of 0.7 for a dominant allele (A) and 0.3 for the recessive allele (a). After a catastrophic event that reduces the population to 25% of its original size, random sampling shows that the new allele frequencies are 0.6 for A and 0.4 for a. Which evolutionary phenomenon best explains this shift in allele frequencies?

**Options:**

A) Gene flow

B) Genetic drift (bottleneck effect)

C) Natural selection

D) Founder effect

**Answer: B) Genetic drift (bottleneck effect)**

**Explanation:**

A severe reduction in population size (a bottleneck) leads to a loss of genetic diversity due to random sampling effects. The observed change in allele frequencies (from 0.7/0.3 to 0.6/0.4) is a classic example of genetic drift resulting from the bottleneck effect.

**Q.25** Conservation biologists use the species–area relationship, expressed as $S = c \cdot Az$ (where S is the number of species, A is the area, c is a constant, and z is typically about 0.25), to estimate biodiversity loss. In a continuous forest of 1000 km², 200 species are observed. Approximately how many species would be expected in a fragment of 100 km²?

**Options:**

A) 75 species

B) 100 species

C) 113 species

D) 150 species

**Answer: C) 113 species**

**Explanation:**

First, determine the constant c using the continuous forest data:

200 = c × (1000)^0.25

Note: (1000)^0.25 = 10^(3×0.25) = 10^0.75 ≈ 5.62

So, c ≈ 200 / 5.62 ≈ 35.59.

Now, apply the relationship to the 100 km² fragment:

S = 35.59 × (100)^0.25

(100)^0.25 = (10^2)^0.25 = 10^(2×0.25) = 10^0.5 ≈ 3.16

S ≈ 35.59 × 3.16 ≈ 112.5

Rounded to the nearest whole number, about 113 species are expected.

**Q.26** A research team is developing a targeted gene knock-out in mammalian cells. Which of the following gene-editing systems is currently the most widely used due to its ease of design and high efficiency?

A. Zinc Finger Nucleases combined with homologous recombination

B. Transcription Activator-Like Effector Nucleases (TALENs)

C. CRISPR-Cas9 with guide RNA

D. Meganucleases based on homing endonuclease motifs

E. CRISPR-Cpf1 with staggered cut generation

**Answer: C. CRISPR-Cas9 with guide RNA**

**Explanation:**

CRISPR-Cas9 is the most popular gene-editing tool because its design relies on a simple, customizable guide RNA to target specific DNA sequences. It offers high efficiency, ease of use, and cost effectiveness compared to earlier methods such as Zinc Finger Nucleases or TALENs.

**Q.27** In a project to produce recombinant human insulin in E. coli, researchers seek a vector/host combination that maximizes protein yield and promotes proper folding. Which of the following is most appropriate?

A. pBR322 in E. coli BL21

B. pUC19 in E. coli DH5α

C. pET vector in E. coli BL21(DE3)

D. pGEX vector in E. coli JM109

E. Lambda phage vector in E. coli K12

**Answer: C. pET vector in E. coli BL21(DE3)**

**Explanation:**

The pET expression system is widely used for high-level expression of recombinant proteins. The BL21(DE3) strain contains the T7 RNA polymerase gene under inducible control, ensuring robust, controlled protein expression and improved yields. This system is optimal for producing human insulin in bacteria.

**Q.28** During eukaryotic DNA replication, which enzyme complex is primarily responsible for the continuous synthesis of the leading strand?

A. DNA polymerase alpha-primase complex

B. DNA polymerase delta

C. DNA polymerase epsilon

D. DNA polymerase beta

E. DNA polymerase gamma

**Answer: C. DNA polymerase epsilon**

**Explanation:**

In eukaryotic cells, DNA polymerase epsilon synthesizes the leading strand continuously during replication. DNA polymerase alpha-primase initiates replication by laying down a short RNA-DNA primer, but subsequent elongation on the leading strand is carried out by DNA polymerase epsilon.

**Q.29** A biotechnology project aims to purify a recombinant protein expressed with a polyhistidine tag. Which purification method will provide the highest specificity?

A. Ion-exchange chromatography

B. Affinity chromatography using Ni-NTA resin

C. Gel filtration chromatography

D. Reverse-phase HPLC

E. Hydrophobic interaction chromatography

**Answer: B. Affinity chromatography using Ni-NTA resin**

**Explanation:**

Ni-NTA (nickel-nitrilotriacetic acid) resin specifically binds to polyhistidine tags on recombinant proteins. This method offers high selectivity and efficiency, allowing for rapid purification of the target protein from bacterial lysates.

**Q.30** In a dihybrid cross between two heterozygous pea plants (YyRr) for two independent traits, which phenotypic ratio among the offspring would best confirm the law of independent assortment?

A. 9:3:3:1

B. 9:7:3:1

C. 12:3:1

D. 9:3:4

E. 1:2:1:2:1

**Answer: A. 9:3:3:1**

**Explanation:**

A 9:3:3:1 phenotypic ratio is the classical outcome of a dihybrid cross involving two independently assorting genes with complete dominance. This ratio confirms Mendel's law of independent assortment.

**Q.31** Environmental factors can trigger heritable changes in gene expression without altering the DNA sequence. Which epigenetic modification is most commonly associated with gene silencing?

A. Histone acetylation

B. DNA methylation of CpG islands

C. Histone methylation at lysine 4

D. Phosphorylation of RNA polymerase II

E. Ubiquitination of histone H2A

**Answer: B. DNA methylation of CpG islands**

**Explanation:**

DNA methylation, particularly in CpG islands within gene promoters, is a major epigenetic mechanism that leads to gene silencing. This modification interferes with transcription factor binding and recruits proteins that condense chromatin, thereby repressing gene expression.

**Q.32** To create a genetically modified crop that is resistant to glyphosate, which genetic modification is most commonly introduced?

A. A gene encoding a modified acetolactate synthase (ALS) enzyme

B. A gene encoding a Bacillus thuringiensis (Bt) toxin

C. A gene encoding a modified 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) enzyme

D. A gene encoding a glycosyltransferase

E. A gene encoding a chitinase

**Answer: C. A gene encoding a modified 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) enzyme**

**Explanation:**

Glyphosate targets the EPSPS enzyme in the shikimate pathway. By introducing a modified EPSPS gene that is insensitive to glyphosate, GM crops become resistant to the herbicide, allowing farmers to control weeds without harming the crop.

**Q.33** In a large population, the frequency of the recessive allele (q) for a gene is 0.3. What is the expected frequency of heterozygotes (2pq) under Hardy-Weinberg equilibrium?

A. 0.42

B. 0.21

C. 0.49

D. 0.48

E. 0.35

**Answer: A. 0.42**

**Explanation:**

Under Hardy-Weinberg equilibrium, if q = 0.3 then p = 1 – 0.3 = 0.7. The heterozygote frequency is 2pq = 2 × 0.7 × 0.3 = 0.42.

**Q.34** In a fermentation experiment using yeast to convert glucose into ethanol, 180 g of glucose is expected to produce 92 g of ethanol theoretically. If an experimental run produces 80 g of ethanol, what is the percent yield?

A. 86.96%

B. 75%

C. 80%

D. 69.57%

E. 95%

**Answer: A. 86.96%**

**Explanation:**

Percent yield = (Actual yield / Theoretical yield) × 100 = (80 g / 92 g) × 100 ≈ 86.96%.

**Q.35** RNA interference (RNAi) is an important tool for gene silencing. Which component of the RNA-induced silencing complex (RISC) is primarily responsible for degrading the target mRNA?

A. Dicer enzyme

B. Argonaute protein

C. RNA polymerase II

D. Ribonuclease P

E. Small nuclear ribonucleoproteins (snRNPs)

**Answer: B. Argonaute protein**

**Explanation:**

Within the RISC, the Argonaute protein is the catalytic subunit responsible for binding to the guide strand (derived from the small interfering RNA) and cleaving the complementary target mRNA, thereby mediating gene silencing.

## Section C - Reason and Assertion

*Questions 36-45 carry 1 mark each. Choose the option that correctly evaluates the assertion and reason.*

### Reason and Assertion Options

- A: Both Assertion and Reason are true, and the Reason is the correct explanation of the Assertion.
- B: Both Assertion and Reason are true, but the Reason is not the correct explanation of the Assertion.
- C: The Assertion is true, but the Reason is false.
- D: The Assertion is false, but the Reason is true.

**Q.36** Assertion (A): The CRISPR–Cas9 system enables highly targeted gene editing primarily because it uses a customizable guide RNA.

**Reason (R): The guide RNA base-pairs with the target DNA sequence, directing the Cas9 nuclease to introduce a double-stranded break at a specific location.**

**Answer: A**

**Explanation: Both the assertion and reason are true, and the reason correctly explains that the base-pairing of the guide RNA with the target sequence is central to the specificity of CRISPR–Cas9 editing.**

**Q.37** Assertion (A): Plasmid vectors are widely used in recombinant DNA technology for cloning and protein expression in bacteria.

**Reason (R): Plasmids replicate independently of the bacterial chromosome, enabling high copy numbers and thus higher yields of the cloned gene product.**

**Answer: A**

**Explanation: Both statements are true. The independent replication of plasmids leads to multiple copies of the inserted gene, which is essential for effective cloning and expression, making the reason a correct explanation of the assertion.**

**Q.38** Assertion (A): DNA methylation in the promoter regions of genes generally leads to gene silencing.

**Reason (R): Methyl groups added to cytosine residues in CpG islands hinder the binding of transcription factors and promote a condensed chromatin structure.**

**Answer: A**

**Explanation: Both the assertion and reason are true, and the reason correctly explains the molecular mechanism by which DNA methylation suppresses gene expression.**

**Q.39** Assertion (A): A dihybrid cross between two heterozygous pea plants (YyRr) yielding a 9:3:3:1 phenotypic ratio confirms the law of independent assortment.

**Reason (R): Independent assortment occurs because genes located on different chromosomes segregate randomly during gamete formation.**

**Answer: A**

**Explanation: Both statements are true, and the reason correctly explains the observed phenotypic ratio as a consequence of the independent segregation of genes on separate chromosomes.**

**Q.40** Assertion (A): Horizontal gene transfer (HGT) is a major mechanism by which bacteria acquire antibiotic resistance.

**Reason (R): HGT allows bacteria to directly incorporate genetic material from unrelated species, thereby increasing genetic diversity and rapid adaptation.**

**Answer: A**

**Explanation: Both the assertion and reason are true, and the reason accurately explains how HGT contributes to the spread of antibiotic resistance among bacteria.**

**Q.41** Assertion (A): During DNA replication in eukaryotic cells, DNA polymerase exhibits proofreading activity that significantly reduces the error rate.

**Reason (R): DNA polymerase possesses a 3′→5′ exonuclease activity that removes misincorporated nucleotides before continuing DNA synthesis.**

**Answer: A**

**Explanation: Both statements are true, and the reason is the precise molecular basis for the proofreading ability of DNA polymerase, thereby reducing replication errors.**

**Q.42** Assertion (A): In vitro fertilization (IVF) is a key assisted reproductive technology that has significantly improved fertility outcomes for couples facing infertility.

**Reason (R): IVF involves the external fertilization of an egg with sperm, allowing embryonic development to be monitored and selected before transferring to the uterus.**

**Answer: A**

**Explanation: Both the assertion and reason are true, and the reason explains the procedure of IVF, which is central to its success in improving fertility outcomes.**

**Q.43** Assertion (A): Codominance in genetics results in a phenotype that simultaneously expresses the traits of both alleles.

**Reason (R): In codominant inheritance, both alleles are fully expressed in heterozygous individuals, such as in the ABO blood group system where type AB blood expresses both A and B antigens.**

**Answer: A**

**Explanation: Both statements are true, and the reason correctly explains the phenomenon of codominance with a well-known example.**

**Q.44** Assertion (A): Messenger RNA (mRNA) is synthesized from DNA during transcription in eukaryotic cells.

**Reason (R): RNA polymerase binds to the promoter region of DNA to initiate transcription, resulting in a complementary mRNA transcript that undergoes subsequent processing.**

**Answer: A**

**Explanation: Both statements are true, and the reason accurately describes the fundamental process of transcription, which is essential for gene expression.**

**Q.45** Assertion (A): Genetically modified crops resistant to glyphosate are typically engineered by introducing a modified version of the EPSPS gene.

**Reason (R): Glyphosate inhibits the EPSPS enzyme in the shikimate pathway; a modified enzyme that is insensitive to glyphosate enables the plant to survive herbicide application.**

**Answer: A**

**Explanation: Both the assertion and reason are true, and the reason correctly explains the molecular basis for glyphosate resistance in genetically modified crops.**

## Section D - Achievers Section

*Questions 46-50 carry 2 marks each and test advanced interdisciplinary reasoning.*

**Q.46** Case Study: Hemodynamic Shear Stress in Coronary Arteries and Atherosclerosis

In coronary arteries, the force exerted by flowing blood on the endothelial (inner) lining is known as wall shear stress. This stress is critical to vascular health—normal shear stress helps maintain endothelial function, while abnormally high or low shear stress can trigger endothelial dysfunction, inflammation, and the progression of atherosclerosis. Under steady, laminar flow, the wall shear stress ($\tau$) in a cylindrical vessel is given by the equation:

$\tau = (4 \mu Q) / (\pi r^3)$

where:

$\mu$ is the dynamic viscosity of blood (assumed constant),

Q is the volumetric flow rate (assumed constant for this scenario), and

r is the vessel radius.

In a healthy coronary artery, the internal diameter is approximately 4 mm (thus, r = 2 mm). In an atherosclerotic region (stenosis), the arterial diameter may reduce to 2 mm (so, r = 1 mm).

**Problem:**

Assume that the volumetric blood flow rate and blood viscosity remain unchanged, and the flow is fully developed and laminar in both the healthy and stenosed regions.

Calculate the factor by which the wall shear stress increases in the stenosed region compared to the healthy region.

Briefly discuss how this elevated shear stress might contribute to further endothelial dysfunction and plaque progression in coronary arteries.

**Options:**

A. The shear stress increases by a factor of 2; this slight increase is unlikely to significantly affect endothelial function.

B. The shear stress increases by a factor of 4; this moderate increase may lead to some endothelial stress but is generally within adaptive limits.

C. The shear stress increases by a factor of 8; this high increase can cause substantial endothelial damage and promote the progression of atherosclerotic plaque.

D. The shear stress increases by a factor of 16; such an extreme increase would likely result in immediate vascular rupture.

**Answer:**

C. The shear stress increases by a factor of 8; this high increase can cause substantial endothelial damage and promote the progression of atherosclerotic plaque.

Detailed Explanation:

Calculating the Increase in Shear Stress:

- For constant μ and Q, the wall shear stress (τ) is inversely proportional to the cube of the vessel radius (r); that is, $\tau \propto 1/(r^3)$.

- Healthy artery:

Diameter = 4 mm → Radius, $r_1$ = 2 mm

(For unit consistency, you could convert mm to cm, but since we are calculating a ratio, the conversion factor cancels out.)

- Stenosed artery:

Diameter = 2 mm → Radius, $r_2$ = 1 mm

- Ratio of shear stresses:

$\tau_2 / \tau_1 = (1 / r_2^3) / (1 / r_1^3) = (r_1 / r_2)^3$

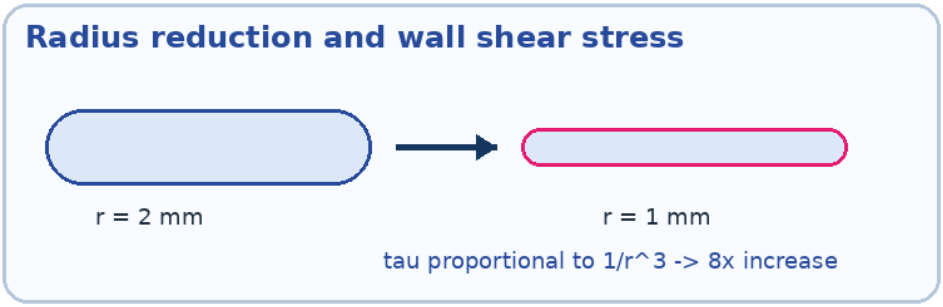
$= (2 \text{ mm} / 1 \text{ mm})^3 = 2^3 = 8$

Thus, the wall shear stress in the stenosed region is 8 times higher than in the healthy region.

Biological Implications:

An 8-fold increase in wall shear stress is significant. Endothelial cells are sensitive to mechanical forces, and while moderate shear stress is protective, excessive shear stress can: - Damage the endothelial lining, - Increase endothelial permeability, - Trigger inflammatory responses, - Lead to the release of pro-atherogenic factors.

These effects collectively contribute to the progression of atherosclerotic plaque by promoting lipid deposition, smooth muscle cell proliferation, and local inflammation.




**Q.47** Case Study : Oxygen Diffusion in Diseased Lungs

**Background:**

In healthy alveoli, oxygen diffuses across a thin membrane into the blood according to Fick's law, where the flux (J) is given by:

$J = (D \times \Delta C)/\delta$

Here, D is the diffusion coefficient (assumed constant), ΔC is the oxygen concentration difference, and δ is the thickness of the alveolar membrane. In conditions such as pulmonary fibrosis, the alveolar membrane thickens. Suppose in healthy lungs $\delta_1 = 0.2$ μm, and in diseased lungs the membrane thickens to $\delta_2 = 0.6$ μm while all other factors remain constant.

**Question:**

By what factor does the oxygen flux decrease in the diseased lung compared to the healthy lung?

**Options:**

A. It decreases by a factor of 2

B. It decreases by a factor of 3

C. It decreases by a factor of 4

D. It decreases by a factor of 6

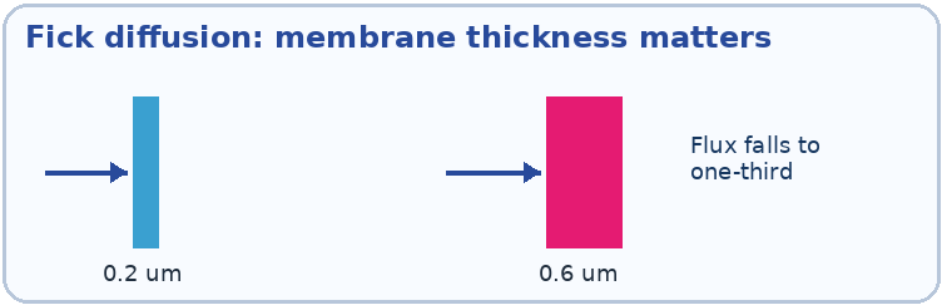
**Answer: B. It decreases by a factor of 3**

**Explanation:**

Since flux $J \propto 1/\delta$, when the thickness increases from 0.2 μm to 0.6 μm,

Flux ratio = $J_2/J_1 = \delta_1/\delta_2 = 0.2/0.6 = 1/3$.

Thus, the oxygen flux in the diseased lung is one-third (i.e., decreased by a factor of 3) that of the healthy lung.




**Q.48** Case Study : Conduction Velocity in Myelinated Axons

**Background:**

In neuroscience, conduction velocity in myelinated axons is often approximately proportional to the axon's diameter. A study shows that in a particular mammalian nerve, the conduction velocity (v) can be modeled as:

$v = k \times d$

where d is the diameter (in μm) and k is a constant. A nerve fiber with a 2-μm diameter conducts at 20 m/s.

**Question:**

If a genetic mutation causes the axon diameter to increase to 3 μm, what is the expected conduction velocity?

**Options:**

A. 25 m/s

B. 30 m/s

C. 35 m/s

D. 40 m/s

**Answer: B. 30 m/s**

**Explanation:**

First, determine the constant k from the original fiber:

20 m/s = k × 2 μm → k = 10 m/s per μm.

For d = 3 μm,

v = 10 × 3 = 30 m/s.

Thus, the conduction velocity increases proportionally to 30 m/s.

**Q.49** Case Study 3: Mechanical Stress on Bone Under Load

**Background:**

According to Wolff's law, bone adapts to the mechanical loads under which it is placed. The stress (σ) on a bone is given by:

$\sigma = F/A$

where F is the applied force and A is the cross-sectional area. In osteoporosis, bone density decreases and the effective cross-sectional area diminishes. Suppose a healthy femur has a cross-sectional area of 5 $cm^2$ and bears a force of 1500 N. In osteoporotic bone, the cross-sectional area decreases by 40%.

**Question:**

By what factor does the mechanical stress increase in the osteoporotic bone under the same load?

**Options:**

A. 1.4 times

B. 1.67 times

C. 2.0 times

D. 2.5 times

**Answer: B. 1.67 times**

**Explanation:**

Healthy area, $A_1 = 5\ cm^2$. In osteoporosis, area reduces by 40%, so:

$A_2 = 5 \times (1 - 0.40) = 3\ cm^2$.

Stress is inversely proportional to area:

$\sigma_2/\sigma_1 = A_1/A_2 = 5/3 \approx 1.67$.

Thus, the stress increases by a factor of approximately 1.67.

**Q.50** Case Study 5: UV Radiation-Induced DNA Damage

**Background:**

Ultraviolet (UV) radiation is known to cause DNA damage. The energy (E) of a photon is given by:

$E = (h \times c)/\lambda$

where $h = 6.626 \times 10^{-34}$ J·s (Planck's constant), $c = 3.0 \times 10^8$ m/s (speed of light), and λ is the wavelength. UV-C radiation (λ = 260 nm) is particularly effective in damaging DNA. A chemical bond in DNA requires about 350 kJ/mol to break.

**Question:**

Calculate the energy per mole of UV-C photons (in kJ/mol). Is the energy per mole of these photons sufficient to break the DNA bond?

**Options:**

A. ~350 kJ/mol; the energy is just sufficient to break the bond.

B. ~450 kJ/mol; the energy is sufficient to break the bond.

C. ~550 kJ/mol; the energy far exceeds the bond energy.

D. ~650 kJ/mol; the energy is excessively high compared to the bond energy.

**Answer: B. ~450 kJ/mol; the energy is sufficient to break the bond.**

**Explanation:**

First, calculate the energy of one UV-C photon:

$\lambda = 260\ nm = 260 \times 10^{-9}$ m

$E = (6.626 \times 10^{-34}\ J{\cdot}s \times 3.0 \times 10^8\ m/s) / (260 \times 10^{-9}\ m)$

$= (1.9878 \times 10^{-25}\ J{\cdot}m) / (260 \times 10^{-9}\ m)$

$\approx 7.64 \times 10^{-19}$ J per photon.

To obtain energy per mole, multiply by Avogadro's number ($6.022 \times 10^{23}$):

Energy per mole = $7.64 \times 10^{-19}$ J $\times$ $6.022 \times 10^{23} \approx 460{,}000$ J/mol

= 460 kJ/mol.

This value (~460 kJ/mol) is slightly higher than the 350 kJ/mol required to break a DNA bond, meaning that UV-C photons have sufficient energy to induce DNA damage.

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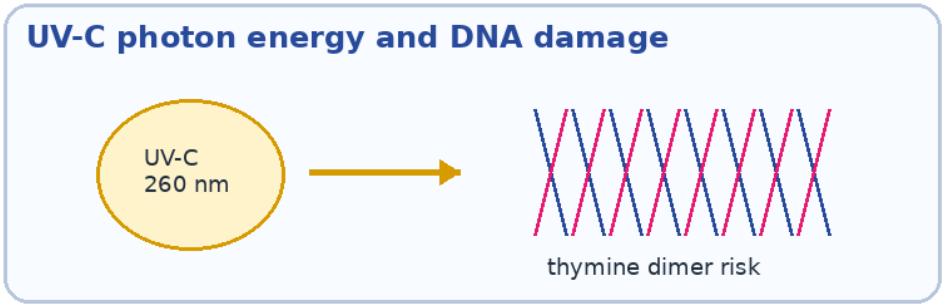

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# Answer Key

Compact answer key for quick checking. Detailed answer text and explanations are included within each question block.

| Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans |
|---|---|---|---|---|---|---|---|---|---|
| 1 | B | 11 | B | 21 | B | 31 | B | 41 | A |
| 2 | B | 12 | C | 22 | C | 32 | C | 42 | A |
| 3 | C | 13 | B | 23 | B | 33 | A | 43 | A |
| 4 | B | 14 | A | 24 | B | 34 | A | 44 | A |
| 5 | A | 15 | C | 25 | C | 35 | B | 45 | A |
| 6 | B | 16 | B | 26 | C | 36 | A | 46 | C |
| 7 | C | 17 | A | 27 | C | 37 | A | 47 | B |
| 8 | B | 18 | B | 28 | C | 38 | A | 48 | B |
| 9 | B | 19 | A | 29 | B | 39 | A | 49 | B |
| 10 | C | 20 | B | 30 | A | 40 | A | 50 | B |

## Formatting and academic corrections applied

- Original guideline mismatch was corrected to 50 questions, 60 minutes, and 55 marks.
- Question-number labels were reduced to a compact left marker instead of a large block.
- Answer and explanation content was preserved and cleaned into a consistent academic layout.
- Useful figures are placed inside relevant question blocks, not in the question-number column.