

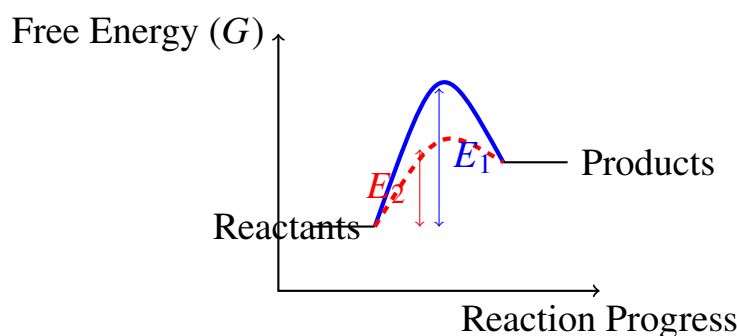


- (B) Intrapleural pressure will immediately equilibrate with atmospheric pressure, abolishing the transpulmonary pressure gradient and causing lung collapse (pneumothorax).
- (C) The operational functional residual capacity ( $FRC$ ) of the non-injured lung segment will scale up by 50%.
- (D) The alveolar air space expands continuously due to passive vacuum suction from the puncture field.

**Q3.** During skeletal muscle excitation-contraction coupling, the biochemical binding of calcium ions to which specific subunit of the troponin complex induces the conformational shift that moves tropomyosin away from the myosin-binding sites on actin?

- (A) Troponin T  
 (B) Troponin I  
 (C) Troponin C  
 (D) Calmodulin

**Q4.** The biochemical configuration below tracks the change in free energy ( $\Delta G$ ) of an endergonic metabolic process under two distinct environmental states. Identify the true statement regarding the energy values marked as  $E_1$  and  $E_2$ .



- (A)  $E_1$  represents the activation energy in the presence of an allosteric activator.
- (B)  $E_2$  represents the activation energy lowered by the stabilization of the transition state by an enzyme.
- (C) The absolute value of  $\Delta G$  for the overall reaction is calculated as  $E_1 - E_2$ .

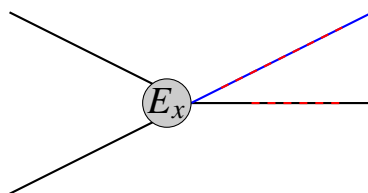


(D)  $E_2$  indicates the un-catalyzed activation energy threshold typical of mammalian physiological systems.

**Q5.** An isolated nerve axon is treated with tetrodotoxin (TTX), which selectively blocks voltage-gated sodium channels. If a suprathreshold depolarizing stimulus is applied to the membrane, the resulting electrical tracing will show:

- (A) A normal action potential with a delayed repolarization phase.
- (B) A rapid, uninhibited reversal of the membrane potential up to +30 mV.
- (C) Absolute failure to generate an action potential phase; only minor passive electronic decay is visible.
- (D) Immediate hyperpolarization down to  $-90$  mV.

**Q6.** The biochemical schematic below details the growing replication fork configuration during nuclear genomic duplication. Identify the structural identity and functional role of the enzyme cluster marked as  $E_x$ .



- (A) DNA Ligase, executing the covalent seal of discontinuous Okazaki fragments.
- (B) DNA Helicase, utilizing ATP hydrolysis to break hydrogen bonds and unwind the double helix ahead of the fork.
- (C) Topoisomerase (DNA Gyrase), relieving torsional strain generated by supercoiling ahead of the replication fork.
- (D) Single-Stranded DNA-Binding Proteins (SSB), stabilizing single strands against re-annealing.

**Q7.** In a multi-factorial genetic analysis, an organism with genotype  $AaBbCcDd$  undergoes a testcross with an individual of genotype  $aabbccdd$ . Assuming all four loci assort completely independently, determine the statistical probability

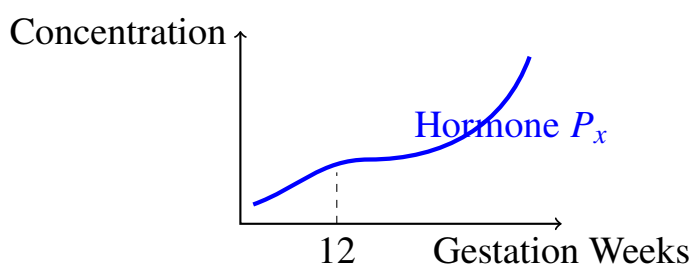
of obtaining an offspring showing the dominant phenotype for at least three of the four traits evaluated:

- (A)  $\frac{1}{16}$
- (B)  $\frac{5}{16}$
- (C)  $\frac{11}{16}$
- (D)  $\frac{3}{8}$

**Q8.** A molecular biology workflow uses an in vitro translation assay containing a selective mutated tRNA molecule. If the anti-codon loop of this specific tRNA has been mutated from 3'-UAC-5' to 3'-ACC-5' but remains charged with its normal original amino acid, Methionine, how will it read an mRNA script?

- (A) It will incorporate Methionine opposite the codon 5'-UGG-3' (Tryptophan).
- (B) It will terminate translation prematurely at the first stop codon layout.
- (C) It will skip translation initiation entirely.
- (D) It will misread every single leucine residue along the structural sequence.

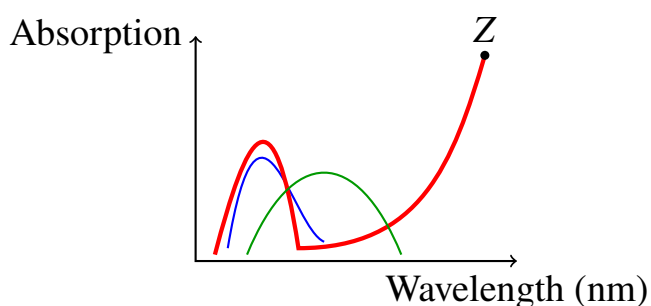
**Q9.** The developmental tracking profile below tracks the steady state output of an essential steroidal derivative during human gestation. Identify the site primarily responsible for the synthesis of hormone  $P_x$  after the first trimester.



- (A) Maternal adrenal cortex matrices
- (B) Maternal Graafian follicle remnants
- (C) The functional syncytiotrophoblast component of the placenta
- (D) Fetal primordial germ layers



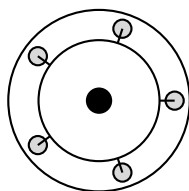
- Q10.** During human spermatogenesis, which distinct cellular stage marks the transition from a diploid state ( $2n$ ) to a true haploid state ( $1n$ ) via the completion of the first reductive meiotic division?
- (A) Spermatogonia type A  
(B) Primary spermatocytes  
(C) Secondary spermatocytes  
(D) Round spermatids
- Q11.** A patient presents with non-functional mutations within the gene encoding the structural glycoprotein zone pellucida protein 3 (ZP3). This molecular defect will directly disrupt which event?
- (A) Blastocyst attachment to the endometrial surface layer.  
(B) Species-specific sperm recognition and binding, which triggers the acrosome reaction.  
(C) The fast block to polyspermy mediated by sodium ion wave influx.  
(D) Fusion of male and female pronuclei configurations during amphimixis.
- Q12.** The graphical plot below shows the relative absorption spectra profiles of three key photosynthetic accessory tracking systems. Identify which compound matches the signature displaying maximum extraction amplitude at point Z.



- (A) Carotenoid matrix systems  
(B) Chlorophyll *b* accessory tracks  
(C) Chlorophyll *a* core reaction complex profile  
(D) Phycobilin antenna setups



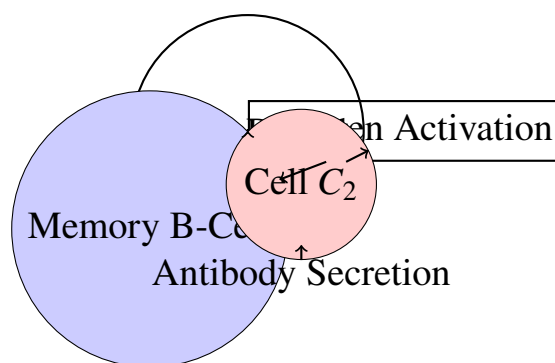
- Q13.** A plant physiology researcher applies a synthetic chemical inhibitor that blocks the active proton pump ( $H^+$ -ATPase) within the plasma membrane of guard cells. What is the immediate impact on stomatal dynamics?
- (A) Immediate hyperpolarization leading to massive  $K^+$  influx and stomatal opening.
  - (B) Failure to establish the electrochemical gradient needed for  $K^+$  accumulation, completely preventing stomatal opening.
  - (C) Accelerated malate synthesis, leading to high turgor pressure states.
  - (D) Rapid, uninhibited passive water influx into the guard cell vacuoles.
- Q14.** Which plant hormone regulates triple-response morphology during germination, triggers leaf senescence, and coordinates triple-point signaling shifts during modern agricultural fruit ripening workflows?
- (A) Indole-3-acetic acid
  - (B) Abscisic acid
  - (C) Ethylene gas molecules
  - (D) Zeatin riboside configurations
- Q15.** The anatomical layout below captures the floral morphology and structural plan of an advanced plant family. Identify the core family name that displays this specific epipetalous, pentamerous, and syncarpous structural plan.



- (A) Fabaceae
- (B) Solanaceae
- (C) Liliaceae
- (D) Brassicaceae



- Q16.** A botanical inventory survey isolates a non-vascular terrestrial plant that features a dominant, photosynthetic gametophytic generation and a dependent sporophyte composed of a foot, seta, and capsule. This structural profiling places the specimen into:
- (A) Pteridophyta
  - (B) Bryophyta (Musci/Liverworts)
  - (C) Gymnospermae
  - (D) Chlorophyceae
- Q17.** Which of the following organisms shows true metameric segmentation, a closed circulatory system, and lateral appendages called parapodia for locomotion?
- (A) *Pheretima posthuma*
  - (B) *Nereis virens*
  - (C) *Hirudinaria granulosa*
  - (D) *Octopus vulgaris*
- Q18.** The cellular tracking layout below displays the functional clonal expansion sequence of an adaptive immune component during a primary infection phase. Identify the structural cell type generated at step  $C_2$ .

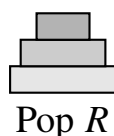


- (A) Cytotoxic T-Lymphocyte
- (B) Mature Plasma Cell specialized for continuous immunoglobulin synthesis
- (C) Natural Killer (NK) cell
- (D) Dendritic antigen-presenting cell

**Q19.** An analytical sample of monoclonal antibodies was developed to block the human immunodeficiency virus (HIV) from entering host cells. This design should target which receptor or co-receptor cluster on human T-cells?

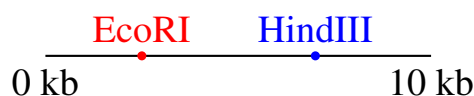
- (A) CD8 platform
- (B) CD4 molecule along with chemokine receptors CCR5 or CXCR4
- (C) B7-1/B7-2 surface proteins
- (D) CD28 costimulatory molecule

**Q20.** The graphical schematic below charts the age structure distribution profiles of three isolated populations ( $P$ ,  $Q$ ,  $R$ ). Choose the option that correctly describes the demographic growth trajectory of population  $R$ .



- (A) Exponentially expanding profile with high birth rates.
- (B) Stable demographic equilibrium where the pre-reproductive group matches the reproductive cohort.
- (C) Declining population trend characterized by a narrow base of pre-reproductive individuals.
- (D) High intrinsic rate of natural increase ( $r$ ).

**Q21.** The restriction endonuclease map layout below sketches the cutting profile of a standard linear plasmid vector. If the vector is fully digested with EcoRI and HindIII simultaneously, determine the number of distinct DNA fragment sizes generated.



- (A) 1 fragment
- (B) 2 fragments



- (C) 3 fragments
- (D) 4 fragments

- Q22.** A geneticist isolates a mutant strain of *Drosophila melanogaster* displaying anomalous homeotic transformations. Molecular mapping reveals a loss-of-function mutation in the ultrabithorax (Ubx) homeobox gene expression zone. This phenotype is an example of a disruption in:
- (A) Segment-polarity tracking arrays
  - (B) Master regulatory genes specifying segment-specific organ identity
  - (C) Maternal effect concentration gradients of Bicoid complexes
  - (D) Non-homologous end-joining DNA repair mechanisms
- Q23.** An RNA-sequencing assay reveals that a specific eukaryotic gene transcribes a primary pre-mRNA that yields five distinct mature functional protein isoforms across different somatic tissues. This physiological plasticity is driven by:
- (A) Variable backward trans-splicing loops
  - (B) Tissue-specific alternative splicing of exon combinations
  - (C) Dynamic changes in the polyadenylation signal sequence
  - (D) Covalent methylation of the 5' guanosine cap structure
- Q24.** A patient undergoing fertility evaluation presents with failure of the blastocyst to embed within the endometrial wall. Diagnostic screenings show abnormally low expression of maternal integrins and L-selectin on the luminal epithelium. This clinical defect directly impairs which developmental window?
- (A) Blastocyst compaction matrix adjustments
  - (B) The apposition and adhesion phases of implantation
  - (C) Cortical granule exocytosis kinetics
  - (D) Epithelial-mesenchymal transition during gastrulation
- Q25.** During human embryonic development, the primordial germ cells (PGCs) migrate from their initial extra-embryonic location to populate the primary



gonadal ridges. Identify the exact site where PGCs are first morphologically detected during early gastrulation:

- (A) Splanchnic mesoderm of the yolk sac wall near the allantois
- (B) Intermediate mesoderm of the pronephric segment
- (C) Ectodermal neural crest lineage pathways
- (D) Inner cell mass amniotic fluid boundary

**Q26.** During the generation of an action potential in the touch-sensitive defensive movement of *Mimosa pudica* leaves, rapid turgor loss occurs within specialized extensor cells. This sudden mechanical collapse is driven by:

- (A) Massive active efflux of calcium ions into the central vacuole
- (B) Rapid efflux of potassium and chloride ions from the symplast to the apoplast, driving osmotic water loss
- (C) Immediate hydrolytic breakdown of structural microfilaments in the petiole
- (D) Sudden up-regulation of aquaporin channel synthesis

**Q27.** A plant biochemistry lab isolates a mutant line of *Zea mays* showing high susceptibility to vivipary (premature seed germination while still attached to the parent plant). This phenotype is caused by a biosynthetically non-functional path in the production of:

- (A) Indole-3-acetic acid (IAA)
- (B) Abscisic acid (ABA)
- (C) Gibberellic acid ( $GA_3$ )
- (D) Brassinolide complexes

**Q28.** An unclassified marine organism is recovered from a continental shelf. It exhibits radial symmetry as an adult, a water vascular system featuring tube feet, a calcified endoskeleton, and lacks a definitive head or excretory organs. This character state configuration places the organism into:

- (A) Ctenophora



- (B) Mollusca (Cephalopoda)
- (C) Echinodermata
- (D) Cnidaria (Scyphozoa)

**Q29.** A critical clinical study maps the immune escape mechanism of a hyper-mutating virus. The pathogen suppresses host target cell surface expression of classical MHC Class I molecules. Despite this suppression, why do the host's Natural Killer (NK) cells still kill the infected cells?

- (A) NK cells utilize membrane-bound IgM to bind free viral capsids.
- (B) The loss of self-MHC Class I removes the inhibitory signal received by NK inhibitory receptors (KIRs), activating NK cytotoxicity.
- (C) NK cells are directly stimulated by bacterial lipopolysaccharides.
- (D) Infected cells secrete high baseline titers of transforming growth factor-beta ( $\text{TGF-}\beta$ ).

**Q30.** An evolutionary ecologist studies two sympatric species of granivorous desert rodents that exploit identical seed resources. Over generations, Species A evolves a narrower foraging jaw structure to process micro-seeds exclusively, while Species B maximizes deep-seed extraction. This adaptive shift illustrates:

- (A) Exploitative competitive exclusion leading to local extinction
- (B) Character displacement resulting from selection to minimize overlapping niche competition
- (C) Apparent competition driven by shared generalist predators
- (D) Directional group selection under a density-independent framework

**Q31.** Calculate the total species richness estimation of an ecological community using the Shannon-Wiener Diversity Index parameter ( $H'$ ). If a community contains exactly four species with perfectly equal abundance distribution ratios ( $p_i = 0.25$  for all species), evaluate the value of  $H'$  using natural logarithms ( $\ln$ ):

- (A) 0.25
- (B) 1.00



(C) 1.386

(D) 2.000

**Q32.** Which of the following biogeochemical cycles features an atmospheric reservoir that is completely inaccessible to primary producers without the catalytic action of symbiotic or free-living prokaryotic nitrogenase multi-subunit complexes?

(A) Phosphorus Cycle

(B) Carbon Cycle

(C) Nitrogen Cycle

(D) Sulfur Cycle

**Q33.** A remote aquatic habitat experiences sudden run-off contamination containing rich concentrations of synthetic orthophosphates and nitrates. The immediate ecological trajectory will show a spike in Biological Oxygen Demand (BOD) due to:

(A) Direct toxic denaturation of dissolved oxygen by chemical ions

(B) Accelerated decomposition of massive algal blooms by aerobic heterotrophic bacteria

(C) Complete cessation of photosynthetic activity by submerged macrophytes

(D) Sudden population crashes of primary zooplankton consumers

**Q34.** According to the equilibrium theory of island biogeography developed by MacArthur and Wilson, which configuration of island geography will sustain the highest species equilibrium richness ( $S^*$ ) at steady state?

(A) Small islands located far from the mainland continent source pool

(B) Large islands located close to the mainland continent source pool

(C) Small islands located close to the mainland continent source pool

(D) Large islands located far from the mainland continent source pool

**Q35.** During a CRISPR-Cas9 gene editing workflow designed to knock out an oncogenic locus, a researcher designs a single guide RNA (sgRNA). For the



Cas9 endonuclease to introduce a double-stranded break at the target site, what structural motif must be present immediately 3' of the genomic target sequence?

- (A) A TATA box promoter segment
- (B) A Protospacer Adjacent Motif (PAM) sequence matching 5'-NGG-3'
- (C) A polyadenylation signal tract
- (D) A palindromic restriction site line

**Q36.** A therapeutic biotechnology project designs a transgenic tobacco line that expresses double-stranded RNA (dsRNA) targeting an essential housekeeping gene of the root-knot nematode *Meloidogyne incognita*. This strategy exploits which mechanism?

- (A) Agrobacterium-mediated tumor induction kinetics
- (B) RNA interference (RNAi) causing post-transcriptional gene silencing via RISC activation
- (C) Covalent competitive inhibition of nematode acetylcholinesterase
- (D) Direct somatic mutation via transposable insertion elements

**Q37.** An analytical biochemistry group uses a Sanger dideoxy sequencing assay to map a gene. If the reaction tube accidentally receives a 10-fold excess concentration of dideoxynucleoside triphosphates (ddNTPs) relative to normal deoxynucleoside triphosphates (dNTPs), what is the technical outcome?

- (A) DNA polymerase will run infinitely without terminating.
- (B) Synthesis will terminate prematurely close to the primer site, yielding mostly short fragments.
- (C) No phosphodiester bonds can be initiated at the primer boundary layer.
- (D) The fluorescent dye molecules will fail to bind the terminal bases.

**Q38.** A modern downstream processing workflow requires the purification of a human recombinant protein expressed in *E. coli* that contains an engineered hexahistidine



tag (6x-His tag) at its amino terminus. Which chromatography matrix should be selected?

- (A) Anion-exchange matrix containing diethylaminoethyl (DEAE) functional groups
- (B) Immobilized metal affinity chromatography (IMAC) utilizing nickel ( $\text{Ni}^{2+}$ ) ions
- (C) Hydrophobic interaction chromatography using phenyl-sepharose resins
- (D) Size-exclusion gel filtration columns with fine pores

**Q39.** To verify whether a transgenic plant line has integrated a foreign transgene into its genomic framework and is actively transcribing it into operational message packages, a molecular validation assay must show positive results on:

- (A) A Southern Blot and a Northern Blot respectively
- (B) An ELISA and a Western Blot assay exclusively
- (C) A Western Blot and an Isoelectric Focusing gel path
- (D) A Northern Blot and a Sanger Sequencing matrix run

**Q40.** During a forensic analysis assay utilizing Polymerase Chain Reaction (PCR) workflows, a laboratory technician forgets to add the critical magnesium chloride ( $\text{MgCl}_2$ ) cofactor solution to the assay mixture. This protocol error will result in:

- (A) Complete failure of Taq DNA Polymerase to coordinate substrate binding and catalyze phosphodiester bond formation.
- (B) Accelerated thermal denaturation of the primer templates at low temperatures.
- (C) Nonspecific primer annealing creating aberrant, uninterpretable band arrays.
- (D) Destruction of the genomic template molecules during the melting stage.



## Detailed Solutions

Q1.

## Solution

**Concept:** Gastric parietal cells secrete intrinsic factor, a glycoprotein essential for safeguarding and carrying cobalamin through the gastrointestinal tract. Autoimmune destruction of these cells eliminates intrinsic factor production, which completely prevents the receptor-mediated endocytosis of the nutrient complex within specialized enterocytes located in the distal ileum.

**Solution:** Autoimmune destruction of gastric parietal cells leads to a condition known as pernicious anemia. Parietal cells are responsible for secreting hydrochloric acid and intrinsic factor. Intrinsic factor is an essential transport glycoprotein that binds dietary cyanocobalamin (Vitamin B12) in the acidic environment of the small intestine, protecting it from enzymatic degradation. The resulting intrinsic factor-vitamin B12 complex travels down the alimentary canal to the distal ileum. There, specialized cubilin receptors recognize the complex and trigger receptor-mediated endocytosis. Without parietal cells, intrinsic factor is entirely absent, causing a total failure of cyanocobalamin absorption in the distal ileum despite adequate dietary intake.

**Final Answer:** Cyanocobalamin (Vitamin B12)

**Answer: (B)**

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Q2.

## Solution

**Concept:** Ventilation mechanics rely on negative intrapleural pressure relative to atmospheric pressure. This negative pressure creates a transpulmonary pressure gradient ( $P_{\text{alveolar}} - P_{\text{intrapleural}}$ ) that acts as a structural vacuum, holding the elastic lung tissue open against its natural tendency to recoil.

**Solution:** The intrapleural space is a thin, fluid-filled potential space maintained at a subatmospheric (negative) pressure due to opposing elastic forces: the chest wall recoils outward while the lung tissue recoils inward. An open breach or puncture in the thoracic wall at point *W* creates a direct physical pathway between the external environment and this sealed intrapleural cavity. Air will immediately rush down its pressure gradient from the atmosphere into the intrapleural space. This influx causes the intrapleural pressure to equilibrate with atmospheric pressure, abolishing the negative pressure environment and reducing the transpulmonary pressure gradient to zero. Without this stabilizing pressure gradient, the natural elastic recoil of the lung tissue is unopposed, causing the affected lung to collapse immediately—a clinical condition known as an open pneumothorax.

**Final Answer:** Loss of transpulmonary pressure causes lung collapse (pneumothorax).

**Answer: (B)**

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Q3.

**Solution**

**Concept:** Skeletal muscle contraction is regulated by calcium binding to thin filament proteins. The troponin heterotrimer acts as a molecular switch where the specialized calcium-binding subunit coordinates divalent ions, triggering a structural shift that repositions tropomyosin and exposes the myosin-binding sites on actin filaments.

**Solution:** The troponin complex is a heterotrimer bound to tropomyosin along the actin thin filaments, consisting of three subunits: Troponin T, Troponin I, and Troponin C. Troponin T anchors the complex to tropomyosin, while Troponin I inhibits the myosin-actin interaction in the resting state. When an action potential depolarizes the sarcolemma and travels down the T-tubules, calcium ions are released from the sarcoplasmic reticulum into the sarcoplasm. These calcium ions bind directly to Troponin C, the specific calcium-binding subunit. This binding event induces a conformational change that pulls the attached tropomyosin deep into the actin groove, exposing the active myosin-binding sites and initiating the cross-bridge cycle.

**Final Answer:** Troponin C

**Answer:** (C)

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Q4.

**Solution**

**Concept:** Biological catalysts alter reaction kinetics without modifying thermodynamic equilibrium. Enzymes accelerate reactions by forming stabilizing non-covalent interactions with the high-energy transition state, which lowers the activation energy barrier ( $E_a$ ) required for reactants to transform into products.

**Solution:** The graph tracks free energy across an endergonic reaction progress pathway. The blue curve shows a high activation energy barrier ( $E_1$ ), which represents the un-catalyzed pathway. The red dashed curve shows a significantly lower activation energy barrier ( $E_2$ ). This reduction in the activation energy threshold is the classic hallmark of enzymatic catalysis. Enzymes achieve this by binding the substrate and stabilizing the high-energy transition state configuration through weak non-covalent interactions. It is critical to note that while the enzyme lowers the activation energy from  $E_1$  to  $E_2$ , it does not alter the free energy of the reactants or products, keeping the net thermodynamic free energy change ( $\Delta G$ ) entirely unperturbed.

**Final Answer:** E2 is the lowered activation energy due to enzyme action.

**Answer:** (B)

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Q5.

**Solution**

**Concept:** Action potential generation requires the sequential activation of voltage-dependent ion channels. Blocking the early voltage-gated sodium channels prevents the rapid influx of sodium ions necessary for membrane depolarization, leaving only passive electronic decay in response to stimulation.

**Solution:** The rapid upstroke or depolarization phase of a neuronal action potential depends entirely on the opening of voltage-gated sodium channels. When a threshold stimulus is reached, these channels open rapidly, allowing sodium ions to rush into the axon along their electrochemical gradient. Tetrodotoxin (TTX) is a potent neurotoxin that binds with high affinity to the extracellular pore of these voltage-gated sodium channels, completely blocking sodium ion conduction. When an axon treated with TTX is exposed to a suprathreshold depolarizing stimulus, it cannot initiate an action potential. Instead, the tracing reveals only minor passive electronic decay that fades across the membrane.

**Final Answer:** No action potential generated; only passive decay occurs.

**Answer:** (C)

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Q6.

**Solution**

**Concept:** DNA replication requires coordinated enzymatic activity ahead of the synthesis fork. Unwinding the parental double helix generates overwinding and torsional strain in the downstream regions, which must be relieved by specialized enzymes that introduce transient breaks in the phosphodiester backbone.

**Solution:** The diagram models a moving replication fork during genomic duplication. As DNA helicase unwinds the double helix at the fork by breaking hydrogen bonds, the DNA molecule ahead of the fork becomes tightly overwound, generating severe positive supercoiling and torsional strain. If left unchecked, this strain would halt replication. The enzyme cluster marked  $E_x$  is positioned ahead of the replication fork to resolve this issue. This enzyme is Topoisomerase (or DNA Gyrase in bacteria), which cleaves one or both strands of the DNA backbone, allows the strands to untwist to relieve the torsional supercoiling, and then religates the covalent phosphodiester bonds.

**Final Answer:** DNA gyrase relieves supercoiling ahead of the replication fork.

**Answer:** (C)

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Q7.

**Solution**

**Concept:** Independent assortment allows alleles at different loci to separate randomly during gamete formation. In a testcross with a fully homozygous recessive individual, the phenotypic distribution of the offspring directly reflects the independent binomial probabilities of inheriting dominant or recessive alleles from the heterozygous parent.

**Solution:** The testcross involves an  $AaBbCcDd$  individual crossed with an  $aabbccdd$  individual. Because the four loci assort completely independently, the probability of an offspring displaying the dominant phenotype for any single trait is exactly  $\frac{1}{2}$ , and the probability of displaying the recessive phenotype is also  $\frac{1}{2}$ . This system follows a binomial distribution where  $n = 4$  separate trials. We need to calculate the probability of obtaining an offspring showing the dominant phenotype for at least three traits, which includes exactly three dominant traits or exactly four dominant traits. Using the binomial formula  $\binom{n}{k} p^k q^{n-k}$ :

$$\text{Probability of exactly 3 dominant traits} = \binom{4}{3} \left(\frac{1}{2}\right)^3 \left(\frac{1}{2}\right)^1 = 4 \times \frac{1}{16} = \frac{4}{16}$$

$$\text{Probability of exactly 4 dominant traits} = \binom{4}{4} \left(\frac{1}{2}\right)^4 \left(\frac{1}{2}\right)^0 = 1 \times \frac{1}{16} = \frac{1}{16}$$

$$\text{Total Probability} = \frac{4}{16} + \frac{1}{16} = \frac{5}{16}$$

**Final Answer:**

**Answer:** (B)

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Q8.

**Solution**

**Concept:** Translation fidelity is determined by complementary base pairing between the mRNA codon and the tRNA anticodon loop. If an anticodon is mutated but remains charged with its original amino acid, it will pair with the new complementary codon on the mRNA, inserting its amino acid at that site.

**Solution:** During translation, the ribosome coordinates protein synthesis based on complementary base pairing between the mRNA codon and the tRNA anticodon loop. The amino acid attached to the tRNA does not influence codon recognition. In this assay, the tRNA molecule carries its original amino acid, Methionine, but its anticodon loop has been mutated to 3'-ACC-5'. According to Watson-Crick base-pairing rules, this mutated anticodon will bind to the complementary mRNA codon running in the opposite direction, which is 5'-UGG-3'. As a result, whenever the ribosome encounters the 5'-UGG-3' codon—which normally encodes Tryptophan—it will misincorporate Methionine instead.

**Final Answer:**

**Answer:** (A)

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Q9.

**Solution**

**Concept:** Gestational endocrinology shifts its anatomical site of synthesis across pregnancy. Progesterone is initially produced by the ovarian corpus luteum to sustain early pregnancy, but after the first trimester, the growing placenta takes over the bulk of steroidogenesis.

**Solution:** The graph tracks the production of hormone  $P_x$ , which increases steadily throughout pregnancy, identifying it as progesterone. During the first several weeks of human gestation, the corpus luteum in the maternal ovary is responsible for secreting progesterone, stimulated by human chorionic gonadotropin (*hCG*). Around weeks 7 to 10, a crucial transition known as the luteal-placental shift occurs. By week 12, the corpus luteum degenerates, and the functional syncytiotrophoblast component of the developing placenta takes over as the primary site of progesterone synthesis, producing large amounts to maintain the endometrial lining for the remainder of gestation.

**Final Answer:** The functional syncytiotrophoblast component of the placenta

**Answer:** (C)

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Q10.

**Solution**

**Concept:** Spermatogenesis involves a progression through mitotic and meiotic divisions. Diploid spermatogonia differentiate into primary spermatocytes, which undergo the first meiotic division to separate homologous chromosomes, reducing the chromosome complement from diploid ( $2n$ ) to haploid ( $1n$ ).

**Solution:** Spermatogenesis begins with diploid ( $2n$ ) spermatogonia undergoing mitotic divisions along the basement membrane of the seminiferous tubules. Some of these cells differentiate into diploid primary spermatocytes. The primary spermatocyte then enters and completes meiosis I, the reductive division where homologous chromosomes are separated into two daughter cells. The completion of this first meiotic division marks the transition to a true haploid state ( $1n$ ), and the resulting cells are called secondary spermatocytes. These secondary spermatocytes quickly enter meiosis II to separate sister chromatids, producing round spermatids.

**Final Answer:** Secondary spermatocytes

**Answer:** (C)

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Q11.

**Solution**

**Concept:** Fertilization requires specific biochemical interactions between gametes. Structural proteins within the oocyte's extracellular matrix act as species-specific receptors that bind complementary proteins on the sperm head, triggering the acrosome reaction required for penetration.

**Solution:** The zona pellucida is a specialized extracellular matrix surrounding the mammalian oocyte. It contains structural glycoproteins, including ZP1, ZP2, and ZP3. Zona pellucida protein 3 (ZP3) functions specifically as the primary receptor for species-specific sperm recognition and binding. When a capacitated sperm binds to the ZP3 glycoprotein, it triggers a signaling cascade that induces the acrosome reaction in the sperm head. This exocytotic event releases hydrolytic enzymes that allow the sperm to digest its way through the zona pellucida. A non-functional mutation in ZP3 prevents sperm binding and halts the acrosome reaction, leading to fertilization failure.

**Final Answer:**

**Answer:** (B)

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Q12.

**Solution**

**Concept:** Photosynthetic pigments are characterized by distinct light absorption spectra. The primary reaction center pigment exhibits two main absorption peaks in the visible light spectrum: a primary blue peak and a secondary red peak near 660–680 nm.

**Solution:** The graph displays the absorption spectra of key photosynthetic pigments. The curve reaching its maximum absorption amplitude at point Z in the long-wavelength red region (around 660–680 nm) corresponds to chlorophyll *a*. Chlorophyll *a* is the core reaction center pigment present in all oxygenic photosynthetic organisms. It absorbs light primarily in the blue-violet and red regions of the spectrum while reflecting green light. Accessory pigments like chlorophyll *b* and carotenoids have different absorption profiles that shift peaks into other blue and green wavelengths to broaden the light absorption spectrum.

**Final Answer:**

**Answer:** (C)

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Q13.

**Solution**

**Concept:** Stomatal opening is regulated by active ion transport across guard cell membranes. Proton pumps generate an electrochemical gradient that drives potassium ion accumulation within the cytoplasm, increasing turgor pressure as water follows osmotically.

**Solution:** Stomatal opening is initiated when membrane-bound  $H^+$ -ATPase proton pumps actively transport hydrogen ions out of the guard cells. This proton extrusion hyperpolarizes the plasma membrane and establishes an electrical and chemical gradient. In response to this negative membrane potential, voltage-gated inward potassium channels open, causing a massive influx of  $K^+$  ions into the guard cells, followed by chloride and malate ions. If a chemical inhibitor blocks these active proton pumps, the guard cells cannot generate the required electrochemical gradient. Consequently, potassium ions do not accumulate, osmotic water movement is blocked, and the stomata remain closed.

**Final Answer:** No electrochemical gradient for  $K^+$  uptake prevents stomatal opening.

**Answer: (B)**

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Q14.

**Solution**

**Concept:** Plant growth and stress responses are coordinated by gaseous regulators. A simple hydrocarbon gas modulates seedling development, accelerates leaf and flower senescence, and triggers autocatalytic respiration surges during fruit ripening.

**Solution:** Ethylene is a unique gaseous plant hormone that regulates several key developmental stages and stress responses. During seed germination, ethylene induces the classic "triple response" in dicot seedlings, which consists of shortening and thickening of the hypocotyl and increased horizontal growth to help the seedling navigate past obstacles in the soil. Furthermore, ethylene promotes leaf and flower senescence and abscission. In agricultural workflows, ethylene acts as the primary signaling molecule that triggers fruit ripening in climacteric fruits by inducing an autocatalytic rise in respiration and up-regulating cell-wall degrading enzymes.

**Final Answer:** Ethylene gas molecules

**Answer: (C)**

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Q15.

**Solution**

**Concept:** Floral symmetry and organ arrangement define plant families. A flower featuring five fused petals, stamens fused directly to the corolla tube, and a superior ovary composed of fused carpels is characteristic of the nightshade family.

**Solution:** The floral diagram illustrates a flower with five fused sepals, five fused petals (pentamerous), and stamens that are attached directly to the inner surface of the petals, an anatomical feature known as epipetalous stamens. The gynoecium in the center shows a bicarpellary, syncarpous (fused carpels) superior ovary. This specific combination of floral characters—pentamerous symmetry, epipetalous stamens, and a syncarpous ovary—is a diagnostic hallmark of the family Solanaceae (the nightshade family), which includes plants such as potatoes, tomatoes, and eggplants.

**Final Answer:** Solanaceae

**Answer: (B)**

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Q16.

**Solution**

**Concept:** Plant divisions are classified by life cycle dominance and anatomical specialization. Non-vascular land plants display a dominant, free-living gametophyte generation, while the diploid sporophyte remains structurally dependent on it throughout its lifespan.

**Solution:** The botanical specimen is a non-vascular terrestrial plant that lacks specialized xylem and phloem tissues. Its life cycle is characterized by an alternation of generations where the haploid gametophyte is the dominant, green, photosynthetic, and independent phase. The diploid sporophyte is physically attached to and nutritionally dependent on the gametophyte, consisting anatomically of a foot, a stalk-like seta, and a spore-producing capsule. These structural and developmental features are characteristic of the division Bryophyta, which encompasses mosses, liverworts, and hornworts.

**Final Answer:** Bryophyta (Musci/Liverworts)

**Answer: (B)**

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Q17.

**Solution**

**Concept:** Coelomate invertebrates are distinguished by segmentation patterns and appendages. Marine annelids exhibit true metamerism, a closed circulatory network, and lateral, unjointed fleshy projections called parapodia that assist in swimming and respiration.

**Solution:** The question asks to identify an organism that displays three specific anatomical features: true metameric segmentation, a closed circulatory loop, and lateral unjointed appendages called parapodia. These characteristics define the phylum Annelida, specifically the class Polychaeta. While *Pheretima* (earthworm) and *Hirudinaria* (leech) are annelids with closed circulatory systems, they lack parapodia. *Octopus* belongs to Mollusca and does not show metameric segmentation. *Nereis virens* (the clam worm) is a marine polychaete annelid that possesses distinct parapodia on each body segment for locomotion and gas exchange.

**Final Answer:**

**Answer: (B)**

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Q18.

**Solution**

**Concept:** Humoral immunity relies on the clonal expansion of activated lymphocytes. Antigen-stimulated B-cells differentiate into long-lived memory cells for secondary responses, and short-lived effector cells specialized for high-rate immunoglobulin synthesis and secretion.

**Solution:** The tracking layout depicts the differentiation pathways of a naive B-lymphocyte following antigen activation during a primary immune response. When a naive B-cell encounters its specific antigen and receives T-cell help, it undergoes rapid clonal expansion and differentiates into two distinct functional lineages. The cell lineage marked  $C_1$  represents memory B-cells, which persist long-term to provide rapid defense during secondary exposures. The lineage marked  $C_2$  represents mature plasma cells. These effector cells are specialized factories containing an extensive rough endoplasmic reticulum, dedicated exclusively to synthesizing and secreting large quantities of soluble antibodies.

**Final Answer:**

**Answer: (B)**

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Q19.

**Solution**

**Concept:** Viral entry depends on binding specific host cell surface receptors. The human immunodeficiency virus utilizes its envelope glycoproteins to bind the CD4 platform on helper T-cells, requiring a secondary interaction with chemokine coreceptors to trigger membrane fusion.

**Solution:** The human immunodeficiency virus (HIV) targets helper T-lymphocytes by exploiting specific cell surface proteins to gain entry into the host cytoplasm. The primary receptor for the viral envelope glycoprotein gp120 is the CD4 molecule. However, binding to CD4 alone is insufficient to trigger viral entry; it induces a conformational change that allows gp120 to interact with a specific G-protein-coupled chemokine co-receptor, either CCR5 or CXCR4. This secondary docking step triggers the viral gp41 protein to mediate fusion between the viral envelope and the host cell membrane. Effective blocking strategies must target this CD4 and chemokine co-receptor complex.

**Final Answer:** CD4 molecule along with chemokine receptors CCR5 or CXCR4

**Answer: (B)**

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Q20.

**Solution**

**Concept:** Population demography is reflected in age-structure pyramids. An inverted pyramid profile features a narrow base of pre-reproductive individuals relative to older cohorts, indicating a birth rate below replacement levels and a declining population size.

**Solution:** The age structure diagram for Population *R* displays an inverted pyramid configuration. In this profile, the lowest tier—representing the pre-reproductive cohort—is significantly narrower than the middle tier representing the reproductive cohort. This narrow base indicates low birth rates over recent generations. Because fewer individuals are entering the reproductive pool to replace the aging cohorts, this demographic distribution leads to a negative intrinsic rate of natural increase ( $r < 0$ ), characterizing a declining population trend.

**Final Answer:** Declining population with a narrow pre-reproductive base.

**Answer: (C)**

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Q21.

**Solution**

**Concept:** Restriction mapping tracks cleavage sites on DNA molecules. Complete enzymatic digestion of a linear DNA fragment cleaves the backbone at every target sequence, producing a total number of fragments equal to the number of internal cut sites plus one.

**Solution:** The diagram shows a linear plasmid vector that is 10 kilobases (kb) long. It contains two unique internal restriction endonuclease cutting sites: one for EcoRI at position 1.5 kb and one for HindIII at position 4.2 kb. Performing a simultaneous double digestion with both enzymes cleaves the linear molecule at both locations. This double cleavage divides the single linear strand into three distinct fragments:

- Fragment 1: From 0 kb to the EcoRI site at 1.5 kb, yielding a size of 1.5 kb.
- Fragment 2: Between the EcoRI site at 1.5 kb and the HindIII site at 4.2 kb, yielding a size of  $4.2 - 1.5 = 2.7$  kb.
- Fragment 3: From the HindIII site at 4.2 kb to the end of the vector at 10 kb, yielding a size of  $10 - 4.2 = 5.8$  kb.

This results in 3 distinct fragment sizes.

**Final Answer:** 3 fragments

**Answer:** (C)

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Q22.

**Solution**

**Concept:** Embryonic spatial pattern formation is controlled by a genetic hierarchy. Homeotic selector (Hox) genes act as master regulators that specify the anatomical identity of individual body segments along the anterior-posterior axis during development.

**Solution:** The ultrabithorax (Ubx) gene in *Drosophila melanogaster* belongs to the highly conserved family of Homeotic (Hox) selector genes. These genes contain a shared homeobox DNA sequence and encode transcription factors that regulate downstream gene networks. Hox genes do not establish segment boundaries or concentration gradients directly; rather, they interpret spatial signals from gap and pair-rule genes to specify the unique anatomical identity of individual body segments. A loss-of-function mutation in Ubx disrupts these master regulatory path signals, causing a homeotic transformation where the third thoracic segment misdevelops into a duplicate second thoracic segment, producing a four-winged fly.

**Final Answer:** Master regulatory genes specifying segment-specific organ identity

**Answer:** (B)

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Q23.

**Solution**

**Concept:** Post-transcriptional modification expands proteomic diversity beyond genomic code limits. Spliceosomes can selectively include or exclude different combinations of exons from a primary transcript, allowing a single gene to encode multiple distinct protein isoforms across different tissues.

**Solution:** Eukaryotic cells possess mechanisms that expand their functional proteome relative to the fixed number of genes in their genome. The primary transcript (pre-mRNA) transcribed from a gene contains alternating protein-coding exons and non-coding introns. Through alternative splicing, the spliceosome can select different combinations of exons, splice sites, or skip specific exons entirely in a tissue-specific manner. This regulatory mechanism allows a single pre-mRNA molecule to generate multiple distinct mature mRNA scripts, which are translated into different functional protein isoforms with specialized properties across various somatic tissues.

**Final Answer:** Tissue-specific alternative splicing of exon combinations

**Answer: (B)**

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Q24.

**Solution**

**Concept:** Blastocyst implantation requires coordinated cell adhesion molecules. Cell surface selectins and integrins on the endometrial epithelium mediate the initial docking, attachment, and stable binding of the embryonic trophoblast layer during the receptive implantation window.

**Solution:** Successful implantation of a human blastocyst requires a highly synchronized sequence of molecular interactions during the uterine receptive phase. This process occurs in three main stages: apposition, adhesion, and invasion. During apposition and adhesion, the luminal epithelium of the maternal endometrium up-regulates cell surface proteins, including L-selectin and various integrins. L-selectin mediates the initial loose tethering or "rolling" of the blastocyst trophoblast layer along the uterine wall, while integrins drive stable structural attachment and firm adhesion. A down-regulation or absence of these cell adhesion molecules prevents the embryo from binding to the uterine wall, impairing the apposition and adhesion phases of implantation.

**Final Answer:** The apposition and adhesion phases of implantation

**Answer: (B)**

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Q25.

**Solution**

**Concept:** Primordial germ cell specification occurs outside the developing gonads. The initial population of germ cells is specified in extra-embryonic tissues before migrating through the dorsal mesentery to colonize the primary gonadal ridges during gastrulation.

**Solution:** During mammalian embryonic development, primordial germ cells (PGCs)—the progenitors of gametes—are not specified within the gonads. Instead, they are first morphologically detected during early gastrulation in an extra-embryonic location: the splanchnic mesoderm of the yolk sac wall, close to the base of the allantois. From this extra-embryonic site, the PGCs undergo amoeboid migration through the hindgut epithelium and travel along the dorsal mesentery to colonize the primary gonadal ridges, where they interact with somatic cells to form the functional ovaries or testes.

**Final Answer:** Splanchnic mesoderm of the yolk sac wall near the allantois

**Answer: (A)**

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Q26.

**Solution**

**Concept:** Plant turgor-driven movements rely on rapid shifts in osmotic pressure. Action potentials trigger a rapid efflux of potassium and chloride ions from the symplast into the apoplast, drawing water out of the vacuoles and causing mechanical collapse of specialized motor cells.

**Solution:** The rapid folding of *Mimosa pudica* leaves in response to touch is an example of a thigmonastic movement driven by changes in turgor pressure within specialized motor cells located in the pulvinus at the base of the petiole. When a stimulus generates an action potential, it travels to the pulvinus and triggers the opening of ion channels. This leads to a rapid efflux of potassium ( $K^+$ ) and chloride ( $Cl^-$ ) ions from the cytoplasm (symplast) into the extracellular spaces (apoplast) of the extensor cells. This sudden loss of ions drops the water potential in the apoplast, causing water to flow rapidly out of the vacuoles via osmosis. The resulting loss of turgor pressure causes the extensor cells to collapse mechanically, folding the leaves.

**Final Answer:** Ion efflux causes osmotic water loss.

**Answer: (B)**

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Q27.

**Solution**

**Concept:** Seed dormancy and germination are regulated by balanced hormone signaling. While gibberellins promote growth and germination, abscisic acid acts as a counter-regulator that enforces seed dormancy and prevents premature germination on the parent plant.

**Solution:** Vivipary refers to the premature germination of seeds while they are still attached to the fruit or parent plant, bypassing the normal seed dormancy phase. Seed dormancy is maintained by the hormone abscisic acid (ABA), which accumulates during seed maturation to inhibit growth and promote desiccation tolerance. In contrast, gibberellic acid (GA) promotes germination by activating hydrolytic enzymes. A mutant line of *Zea mays* that is highly susceptible to vivipary typically harbors a genetic defect in the biosynthetic pathway for abscisic acid, or has non-functional ABA receptors. Without active ABA signaling, the inhibitory effect on germination is lost, allowing the embryo to grow prematurely.

**Final Answer:**

**Answer:** (B)

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Q28.

**Solution**

**Concept:** Echinoderm morphological traits combine ancestral and specialized features. They are characterized by secondary pentaradial symmetry as adults, a calcareous endoskeleton, and a unique water vascular system connected to muscular tube feet used for locomotion.

**Solution:** The combination of radial symmetry as an adult, a calcified endoskeleton composed of ossicles, and the complete absence of centralized excretory or cephalic structures points to the phylum Echinodermata. A defining hallmark of echinoderms is their water vascular system, a network of fluid-filled canals that branch into muscular projections called tube feet (podia). These tube feet utilize hydrostatic pressure to drive locomotion, assist in food capture, and facilitate gas exchange. While organisms in Cnidaria or Ctenophora display radial symmetry, they lack a water vascular system or a calcified endoskeleton.

**Final Answer:**

**Answer:** (C)

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Q29.

**Solution**

**Concept:** Natural Killer cell activation is governed by a balance of opposing surface receptors. The binding of killer inhibitory receptors (KIRs) to self-MHC Class I molecules normally suppresses cytotoxicity, while the loss of this interaction triggers target cell lysis.

**Solution:** Natural Killer (NK) cells monitor host tissues using a balance of signals from activating and inhibitory surface receptors. Inhibitory receptors on the NK cell, such as killer-cell immunoglobulin-like receptors (KIRs), recognize and bind to classical MHC Class I molecules, which are expressed on all healthy nucleated host cells. This binding sends a negative signal that suppresses NK cell cytotoxicity, protecting healthy tissue. Many viruses down-regulate host MHC Class I expression to escape recognition by cytotoxic T-lymphocytes. However, this loss of self-MHC Class I eliminates the inhibitory signal received by the NK cell's KIRs. This activation shift, known as the "missing-self" hypothesis, triggers the NK cell to release perforins and granzymes to lyse the infected cell.

**Final Answer:** Loss of self-MHC I activates NK cell cytotoxicity.

**Answer: (B)**

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Q30.

**Solution**

**Concept:** Interspecific competition drives evolutionary niche divergence. Sympatric species exploiting overlapping resources face selective pressure to diversify their phenotypic traits, which minimizes competitive overlap and allows stable co-existence.

**Solution:** When two species with overlapping ecological niches live in the same geographic region (sympatry), they compete intensely for shared, limiting resources. This resource competition exerts strong selective pressure on both populations to minimize niche overlap. Over generations, individuals possessing phenotypic traits that allow them to exploit alternative resources will experience higher fitness. This evolutionary divergence in physical or behavioral traits between sympatric populations is known as character displacement. The divergence in jaw morphology between Species A and Species B reduces direct competition for the same seed sizes, facilitating stable coexistence within the shared ecosystem.

**Final Answer:** Character displacement reducing niche competition.

**Answer: (B)**

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Q31.

**Solution**

**Concept:** The Shannon-Wiener Index quantifies community diversity based on species richness and evenness. When all species are distributed with perfectly equal abundance ratios, the diversity value simplifies mathematically to the natural logarithm of total species richness.

**Solution:** The Shannon-Wiener Diversity Index ( $H'$ ) is calculated using the following equation:

$$H' = - \sum_{i=1}^S p_i \ln(p_i)$$

where  $S$  is the total species richness and  $p_i$  is the relative abundance proportion of the  $i$ -th species. The community contains exactly four species ( $S = 4$ ) with perfectly equal abundance distribution ratios ( $p_i = 0.25$  for all four species). Substituting these values into the index formula gives:

$$H' = - [4 \times (0.25 \times \ln(0.25))]$$

$$H' = - [1 \times \ln(0.25)] = - \ln(0.25)$$

Using the properties of logarithms,  $\ln(0.25) = \ln\left(\frac{1}{4}\right) = -\ln(4)$ . Therefore:

$$H' = -(-\ln(4)) = \ln(4) \approx 1.386$$

**Final Answer:**

**Answer:** (C)

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Q32.

**Solution**

**Concept:** Biogeochemical cycles depend on chemical transformations to make nutrients bioavailable. Atmospheric nitrogen gas features a strong covalent triple bond that cannot be fixed by plants or animals without the specialized nitrogenase complexes found in prokaryotes.

**Solution:** The nitrogen cycle features a massive atmospheric reservoir, as nitrogen gas ( $N_2$ ) makes up approximately 78% of the Earth's atmosphere. However, despite its abundance, this atmospheric pool is completely inaccessible to primary producers and eukaryotes. The two nitrogen atoms in  $N_2$  are joined by an exceptionally strong covalent triple bond. Breaking this bond requires a large amount of activation energy, which can only be provided biologically by specialized prokaryotes. These include symbiotic bacteria like *Rhizobium* or free-living strains like *Azotobacter*, which express the nitrogenase enzyme complex to reduce atmospheric nitrogen gas into bioavailable ammonia ( $NH_3$ ).

**Final Answer:**

**Answer:** (C)

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Q33.

**Solution**

**Concept:** Cultural eutrophication alters aquatic oxygen dynamics. An influx of limiting nutrients triggers rapid algal blooms; when these blooms die, populations of aerobic heterotrophic bacteria expand rapidly to decompose the organic matter, depleting dissolved oxygen levels.

**Solution:** When an aquatic habitat receives an agricultural run-off containing high concentrations of orthophosphates and nitrates, it induces cultural eutrophication. These ions remove the nutrient limitations that normally constrain primary production, triggering a rapid population explosion of algae and cyanobacteria known as an algal bloom. As this massive biomass exhausts the nutrients, the algae die off simultaneously. Aerobic heterotrophic bacteria decompose this dead organic material, expanding rapidly and consuming large amounts of dissolved oxygen through cellular respiration. This soaring oxygen consumption causes a sharp spike in Biological Oxygen Demand (BOD), depleting dissolved oxygen and threatening aquatic animals.

**Final Answer:** Rapid decomposition of algal blooms by aerobic bacteria.

**Answer: (B)**

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Q34.

**Solution**

**Concept:** The equilibrium theory of island biogeography balances immigration and extinction dynamics. Species richness values are governed by an island's size, which dictates extinction rates, and its isolation distance from the mainland source pool, which determines immigration rates.

**Solution:** The MacArthur-Wilson Equilibrium Theory of Island Biogeography states that the species equilibrium richness ( $S^*$ ) on an island is determined by a balance between immigration rates of new species and extinction rates of established species.

- Immigration rates are primarily influenced by isolation distance: islands located closer to the mainland continent source pool have higher immigration rates because they are easier for dispersing organisms to reach.
- Extinction rates are primarily driven by island size: larger islands support larger population sizes and provide a wider variety of ecological niches, reducing the likelihood of stochastic extinctions.

Therefore, the highest species equilibrium richness is sustained on islands that are both large and located close to the mainland.

**Final Answer:** Large islands located close to the mainland continent source pool

**Answer: (B)**

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Q35.

**Solution**

**Concept:** The CRISPR-Cas9 system utilizes specific genomic motifs to prevent self-targeting. The endonuclease relies on a guide RNA to find the target sequence, but cleavage requires a short, conserved neighboring nucleotide sequence located immediately 3' of the target site.

**Solution:** In the CRISPR-Cas9 gene-editing system, target specificity is guided by a single guide RNA (sgRNA) that base-pairs with a genomic sequence. However, complementary base pairing alone is insufficient for enzyme activation. For the Cas9 endonuclease to bind, change conformation, and introduce a double-stranded break, a short, conserved nucleotide sequence known as the Protospacer Adjacent Motif (PAM) must be present immediately 3' of the target sequence in the genomic DNA. For the classic *Streptococcus pyogenes* Cas9 enzyme, this essential PAM motif follows the sequence configuration 5'-NGG-3', where N represents any nucleotide.

**Final Answer:** A Protospacer Adjacent Motif (PAM) sequence matching 5'-NGG-3'

**Answer: (B)**

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Q36.

**Solution**

**Concept:** Transgenic pest-defense strategies exploit cellular gene-silencing mechanisms. Expression of complementary double-stranded RNA sequences matching target genes triggers host processing machinery to degrade matching transcripts, silencing essential pathways in the feeding pathogen.

**Solution:** This biotechnology strategy utilizes RNA interference (RNAi) to protect transgenic tobacco crops from parasitic root-knot nematodes (*Meloidogyne incognita*). The transgenic plant is engineered to express a double-stranded RNA (dsRNA) sequence that matches an essential housekeeping gene within the nematode. When the nematode feeds on the plant tissues, it ingests these dsRNA molecules. Inside the nematode's cells, the core enzyme Dicer processes the dsRNA into small interfering RNAs (siRNAs). These siRNAs guide the RNA-Induced Silencing Complex (RISC) to bind and degrade the nematode's complementary mRNA transcripts, causing post-transcriptional gene silencing that disrupts essential cellular pathways and kills the parasite.

**Final Answer:** RNAi-mediated post-transcriptional gene silencing.

**Answer: (B)**

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Q37.

**Solution**

**Concept:** Sanger sequencing relies on a precise ratio of chain-extending and chain-terminating nucleotides. Dideoxynucleoside triphosphates lack the 3'-hydroxyl group required to form phosphodiester bonds; an excessive concentration causes premature termination near the primer site, preventing the synthesis of longer fragments.

**Solution:** Sanger dideoxy sequencing relies on a precise balance between standard deoxynucleoside triphosphates (dNTPs), which allow elongation, and modified dideoxynucleoside triphosphates (ddNTPs), which terminate synthesis. The modified ddNTPs lack the essential 3'-hydroxyl group (-OH) on the ribose ring required to form a phosphodiester bond with the next incoming nucleotide. If a reaction tube receives an accidental 10-fold excess of ddNTPs relative to dNTPs, the probability of DNA polymerase incorporating a chain-terminating ddNTP increases dramatically. Consequently, elongation will terminate prematurely very close to the primer site, yielding a pool of short fragments and preventing the synthesis of longer fragments needed to read the full sequence.

**Final Answer:** Premature termination produces short DNA fragments.

**Answer: (B)**

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Q38.

**Solution**

**Concept:** Recombinant protein purification utilizes specific affinity tags. Engineered arrays of imidazole rings exhibit strong coordination chemistry with transition metal ions, allowing targeted isolation using chelated matrix columns.

**Solution:** The purification of a recombinant protein engineered with a hexahistidine tag (6x-His tag) takes advantage of the coordination chemistry between the imidazole rings of histidine residues and transition metal ions. The ideal method for this application is Immobilized Metal Affinity Chromatography (IMAC). In this technique, a chromatography matrix (such as agarose or sepharose) is chemically conjugated to a chelating agent that holds divalent transition metal cations, most commonly nickel ( $\text{Ni}^{2+}$ ). When the crude bacterial cell lysate passes through the column, the 6x-His tags bind tightly to the immobilized nickel ions, while untagged bacterial host proteins flow through. The target protein is then eluted by adding imidazole.

**Final Answer:** Immobilized metal affinity chromatography (IMAC) utilizing nickel ( $\text{Ni}^{2+}$ ) ions

**Answer: (B)**

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Q39.

**Solution**

**Concept:** Transgene validation requires analyzing both genomic integration and transcriptional activity. Blotting techniques isolate and detect specific macromolecules from complex mixtures using complementary labeled probes to verify the presence of DNA and RNA targets.

**Solution:** To confirm the successful integration and functional expression of a transgene, a researcher must analyze both the host genome and its transcription products.

- First, a Southern blot is used to verify genomic integration. This technique involves isolating genomic DNA, digesting it with restriction enzymes, separating the fragments via gel electrophoresis, transferring them to a membrane, and hybridizing them with a labeled DNA probe to confirm the presence of the transgene.
- Second, a Northern blot is used to verify active transcription. This technique follows a similar workflow but isolates cellular RNA instead of DNA, separating the transcripts on a denaturing gel to confirm that the transgene is being transcribed into mature mRNA message packages.

**Final Answer:** A Southern Blot and a Northern Blot respectively

**Answer: (A)**

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Q40.

**Solution**

**Concept:** DNA polymerases require divalent cation cofactors to catalyze nucleotide addition. Magnesium ions coordinate the phosphate groups of incoming dNTPs and lower the activation energy for nucleophilic attack, making them essential for phosphodiester bond formation during PCR.

**Solution:** Taq DNA Polymerase, like all DNA polymerases, relies on divalent magnesium cations ( $Mg^{2+}$ ) as an essential cofactor to catalyze DNA synthesis. The  $Mg^{2+}$  ions form coordinate bonds with the negative phosphate groups on the incoming deoxynucleotide triphosphates (dNTPs) and the DNA template backbone. This stabilization polarizes the alpha-phosphate group, facilitating the nucleophilic attack by the 3'-hydroxyl group of the primer to form a new phosphodiester bond. Omitting magnesium chloride ( $MgCl_2$ ) prevents the enzyme from coordinating substrate binding, resulting in a complete failure of the PCR amplification workflow.

**Final Answer:** Taq polymerase fails to bind substrate and form phosphodiester bonds.

**Answer: (A)**

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## Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	B	2	B	3	C	4	B	5	C
6	C	7	B	8	A	9	C	10	C
11	B	12	C	13	B	14	C	15	B
16	B	17	B	18	B	19	B	20	C
21	C	22	B	23	B	24	B	25	A
26	B	27	B	28	C	29	B	30	B
31	C	32	C	33	B	34	B	35	B
36	B	37	B	38	B	39	A	40	A

