Quiz 4: Fundamentals of Biology II by Dr. Gaurav Ahuja Date: 26/11/2025

Max Marks = 36 (16 + 20)

Multiple Choice Questions (2 x 8 = 16 marks, 0.5 marks negative)

MCQ 1: C. Variable regions of light and heavy chains
MCQ 2: B. ACTH
MCQ 3: C. Voltage-gated potassium channels
MCQ 4: B. Bottleneck effect
MCQ 5: B. A hypothetical common ancestor
MCQ 6: C. IgG
MCQ 7: C. Hypothalamus
MCQ 8: B. Myelinated axons

Subjective Questions: Attempt any 4 Questions (5 marks each)

Ques 1: What structural features allow an antibody to specifically recognize an antigen? How do affinity maturation and class switching enhance the precision and strength of the adaptive immune response?

Ans: Antibodies specifically recognize antigens due to the variable (V) regions present on the light and heavy chains. These regions form the antigen-binding site, also called the paratope, which has a unique three-dimensional shape and chemical properties that complement the antigen's epitope. The CDRs (complementarity-determining regions)—particularly CDR3—are the most diverse parts and largely determine antigen specificity. The overall Y-shaped structure, with flexible hinge regions, also allows better binding to antigens.

Affinity maturation occurs in germinal centers after antigen exposure. Through somatic hypermutation of the V-region genes and selection of B cells with higher antigen affinity, antibodies progressively become stronger and more specific binders. This enhances the precision of the immune response.

Class switching (isotype switching) changes the antibody's constant (C) region of the heavy chain (e.g., IgM → IgG → IgA → IgE) without altering antigen specificity. This allows the same antigen-binding site to be paired with different effector functions—such as improved opsonization, mucosal immunity, or allergy responses—making the immune response more versatile and effective.

Ques 2: How does the hypothalamus–pituitary–adrenal (HPA) axis coordinate the body's response to stress? What mechanisms ensure feedback regulation of hormone release across these three endocrine tiers?

Ans: The HPA axis is a three-tiered endocrine system that coordinates the body's response to physical or psychological stress. Stress signals first activate the hypothalamus, which releases CRH (corticotropin-releasing hormone) into the hypophyseal portal system. CRH stimulates the anterior pituitary to secrete ACTH (adrenocorticotropic hormone). ACTH then travels through the bloodstream to the adrenal cortex, where it triggers the production and release of cortisol. Cortisol promotes energy mobilization, increases blood glucose, and modulates immunity, enabling the body to cope with stress.

Feedback regulation is maintained through negative feedback loops at multiple levels. Rising cortisol levels bind to glucocorticoid receptors in both the hypothalamus and anterior pituitary, inhibiting further secretion of CRH and ACTH. This prevents excessive cortisol production and maintains hormonal balance. Additionally, specialized hypothalamic neurons monitor circulating cortisol levels to fine-tune hormone release. These feedback mechanisms ensure that the stress response is activated when needed but turned off once homeostasis is restored.

Ques 3: What molecular events initiate the rapid depolarization during an action potential? How do absolute and relative refractory periods guarantee unidirectional signal propagation along the axon?

Ans: The rapid depolarization phase of an action potential is initiated when a stimulus brings the membrane potential to threshold, causing voltage-gated sodium (Na^+) channels to open. These channels open very quickly, allowing a large influx of Na^+ down its electrochemical gradient. This sudden entry of positive ions makes the inside of the neuron sharply more positive, producing the rapid upswing of the action potential.

After this, the Na^+ channels become inactivated, and voltage-gated potassium (K^+) channels open, beginning repolarization.

The absolute refractory period occurs when Na^+ channels are completely inactivated and cannot reopen, regardless of stimulus strength. This prevents any new action potential from being generated immediately, ensuring that the impulse cannot reverse direction.

The relative refractory period follows, during which some Na^+ channels reset, but K^+ efflux keeps the membrane hyperpolarized. A stronger-than-normal stimulus is required to initiate another action potential. These two refractory periods together ensure that action potentials propagate unidirectionally along the axon and do not move backward into regions that have just fired.

Ques 4: What conditions must be met for a population to remain in Hardy–Weinberg equilibrium? How do evolutionary forces such as genetic drift and gene flow alter allele frequencies over generations?

Ans: A population remains in Hardy–Weinberg equilibrium only if several strict conditions are met, ensuring that allele and genotype frequencies remain constant across generations. These conditions are:

1. Large population size to prevent random changes in allele frequencies.
2. No mutations that could introduce new alleles or alter existing ones.
3. No migration (gene flow) into or out of the population.
4. Random mating, with no sexual selection or preference.
5. No natural selection, meaning all genotypes have equal reproductive success.

When any of these assumptions are violated, evolutionary forces begin to alter allele frequencies. Genetic drift, which is especially strong in small populations, causes random changes in allele frequencies due to chance events. It can lead to the loss of alleles and reduced genetic variation over generations. Gene flow, the movement of individuals or gametes between populations, introduces new alleles or changes their proportions, making populations more genetically similar over time. Both forces drive evolution by shifting allele frequencies away from Hardy–Weinberg predictions.

Ques 5: What defines a clade in a phylogenetic tree, and how does it differ from more general branching patterns? How do branch lengths and topology together provide insight into evolutionary relationships and divergence times?

Ans: A clade is a group of organisms that includes a common ancestor and all of its descendants. It represents a monophyletic group, meaning the entire evolutionary lineage stemming from one node is included.
This differs from general branching patterns because not every branching group forms a true clade—e.g., paraphyletic groups exclude some descendants, and polyphyletic groups combine unrelated lineages. A clade is strictly defined by ancestry, not by superficial similarity.

The topology of a phylogenetic tree (the order of branching) shows the *pattern of relationships*, such as which species share a more recent common ancestor. Topology tells us who is more closely related to whom, independent of time.

Branch lengths add an additional layer of information. When they represent genetic change or time, longer branches indicate greater divergence or older evolutionary separation.
Thus, combining topology + branch length allows interpretation of both:

- evolutionary relationships (via branching order), and
- approximate divergence times or amount of molecular change (via branch length).