



2025 Mitosisphere September Challenge

Part A (MCQ)

Anatomy & Physiology (2 Questions)

1. As LeBron James retires after year 23, he begins his coaching career at the Miami Heat. One of the players, Cooper Flagg, begins to experience fatigue and muscle cramps during light training. When a biopsy of the gastrocnemius was done there was a large accumulation of lipid droplets and a mutation in the CPT1 gene, which encodes an enzyme part of the carnitine shuttle. LeBron now is confused - what is the most likely cause of Flagg's symptoms based on the findings?
- A. Carnitine shuttle dysfunction leads to increased ketone body formation which lowers blood pH and impairs troponin C binding
 - B. Increased activation of glycolytic pathways causes lactic acidosis that impairs Ca^{2+} reuptake into the sarcoplasmic reticulum
 - C. Mutations in CPT1 impair fatty acid transport into mitochondria, reducing aerobic ATP production from lipids during prolonged low-intensity exercise
 - D. Impaired CPT1 function increases mitochondrial Ca^{2+} uptake, reducing cross-bridge detachment and causing sustained contractions
 - E. CPT1 normally regulates troponin-tropomyosin displacement during muscle contraction, so loss-of-function reduces sarcomere cycling

Solution: B, CPT1 transports long-chain fatty acids into mitochondria. Without it, fatty acid oxidation is impaired, especially important in endurance or low-intensity activity. Glycolysis is not primarily activated in low-intensity states (A), and ketone formation is decreased (not increased) without FAO (C). Calcium misregulation and contractile protein misattribution are incorrect (D/E).

2. A 12 year-old kid with frequent urination, constant thirst, and weight loss is diagnosed with Type 1 Diabetes Mellitus. Which of the following best explains his glycosuria despite normal kidney function?
- A. Defective aquaporins in the collecting duct leading to glucose loss
 - B. Saturation of glucose reabsorption due to excessive plasma glucose
 - C. Increased activity of aldosterone reducing sodium-glucose co-transport
 - D. Overactivation of SGLT2 transporters in the proximal tubule
 - E. Downregulation of GLUT4 in proximal tubular epithelial cells

Solution: *B, when someone has hyperglycemia, glucose exceeds the renal threshold and saturates SGLT transporters.*

Cell Biology (2 Questions)

3. A researcher is studying the packing of genetic material under different stages of the cell cycle. He has noticed that during some periods, the DNA appears as though it looks like beads on a string. He notes the structure of these beads and concludes that these must be the distinct units that the DNA is packed into. However, later, to his surprise, he notices that the DNA looks highly condensed and is packaged into bundles noticeably thicker than the distinct units he noticed earlier. Upon further inspection he realizes that this is due to those units being packaged into zigzags of tetramers. Which of the following proteins is likely responsible for holding these tetramers together, so that they can condense so tightly?

- A. H1
- B. H2A
- C. H2B
- D. H3
- E. H4

Solution: *A, This higher-order compaction is stabilized by the linker histone H1, which binds to the nucleosome at the DNA entry/exit sites and helps pack them tightly.*

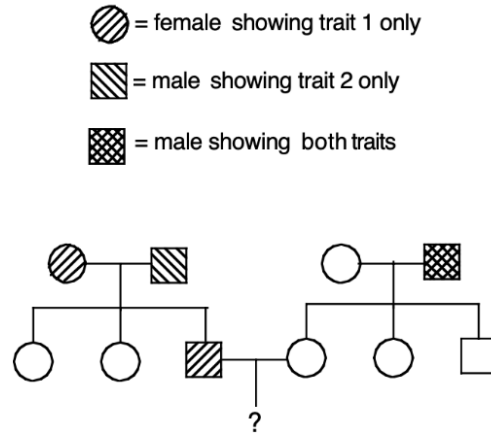
Mycota is a lysosome-bound enzyme but when she woke up, she found herself alone in the cytosol (meaning she has detached from her bestfriend lysosome). Surprisingly, her primary sequence has not changed, but microscopy reveals a failure to form vesicles at the trans-Golgi network. What is most likely the cause?

- A. R-SNARE overactivation
- B. COPI vesicle overexpression
- C. Defective glycosylation in the rough ER
- D. Clathrin malfunction
- E. Lysosome damage

Solution: *D, Clathrin-coated vesicles bud from the trans face of Golgi body to deliver enzymes to lysosomes (via mannose-6-phosphate receptors). So if clathrin fails, enzymes are not packaged properly and thus may remain in the cytosol and be misdirected to somewhere else.*

Genetics (2 Questions)

Use the following information to answer the following questions.



Shown above is a pedigree for 2 recessive traits.

6. Assuming that both traits are due to linked autosomal genes that are 10 cM apart, calculate the probability that the indicated child will have both recessive traits.
- A. 0.125
 B. 0.176
 C. 0.225
 D. 0.255
 E. 0.275

Solution: C, Assume trait one (held by P-1) is gene A and trait two (held by P-2) is gene B. Individual II-1 must inherit both recessive alleles from her parents (i.e. have the genotype *aabb*) to have both recessive traits. It can be assumed that P-1 is recessive for trait A and dominant for trait B (genotype *aaBB* or *aaBb*), and that P-2 is recessive for trait B and dominant for trait A (genotype *AAbb* or *Aabb*). This means that individual I-3 can have either genotype *aaBB* or *aaBb* (since she isn't affected by "disease B"), but to pass on the recessive allele to individual II-1, I-3 must have the genotype *aaBb*, as they must produce the gamete *ab* (which is not possible with *aaBB*). Because individual P-4 is *aabb*, as they are affected by both diseases, this means individual I-4 must have the genotype *AaBb*, as they are not affected by either disease but inherit the *a* and *b* alleles from her father. I-3's chances to produce the *ab* gamete is given here: he has the genotype *aaBb*, and given the recombination the frequency, he has a 0.9 chance to produce nonrecombinant gametes *aB* and *ab*, and a 0.1% chance to produce recombinant gametes

aB and ab. Therefore, his total chance to produce an ab gamete is 0.5 (given by $0.9 / 2 + 0.1 / 2$). Individual I-4, who has a genotype of AaBb has a 0.9 chance to produce nonrecombinant gametes AB or ab, and a 0.1 chance to produce recombinant gametes Ab and aB. Therefore, her chance to produce an ab gamete is given by $0.9/2 = 0.45$. Therefore, individual II-1's chance to get both recessive traits is $(0.5)(0.45) = 0.225$.

Assuming that both traits are 10 cM apart on the X chromosome, what is the probability that a male child will have both recessive traits?

- A. 0.35
- B. 0.4
- C. 0.45
- D. 0.5
- E. 0.55

Solution: C, Because a male only inherits his X chromosome from his mother, we only have to consider individual I-4's genotype here; individual I-3's genotype is irrelevant because he doesn't pass down an X Chromosome to his son. Individual I-3 has the genotype X^AB X^ab, as she receives the X^ab chromosome from her father, but since she isn't affected by either disease, the other chromosome must be dominant in both alleles. Therefore, because the son requires the X^ab gene to be passed down to be doubly recessive, individual I-3 must pass down the intact, nonrecombinant chromosome X^ab. The probability of this is $(1-0.1)/2 = 0.45$.

Plant Biology (1 Question)

6. It's late summer and monk Daniel decided to do some experiment on his newly grown tomatoes. He had intentionally blocked the chromoplast development so the plastids in the ripening fruits can remain as chloroplasts. Surprisingly, the tomatoes stay green but accumulate abnormally high levels of starch. In a separate mutant, roots fail to grow normally and show a dramatic reduction in starch granules, even though leaf photosynthesis seems unaffected. Looking at these phenotypes, Daniel is confused and wants you to remind him of how plastid specialization works. Which explanation best accounts for the observations?

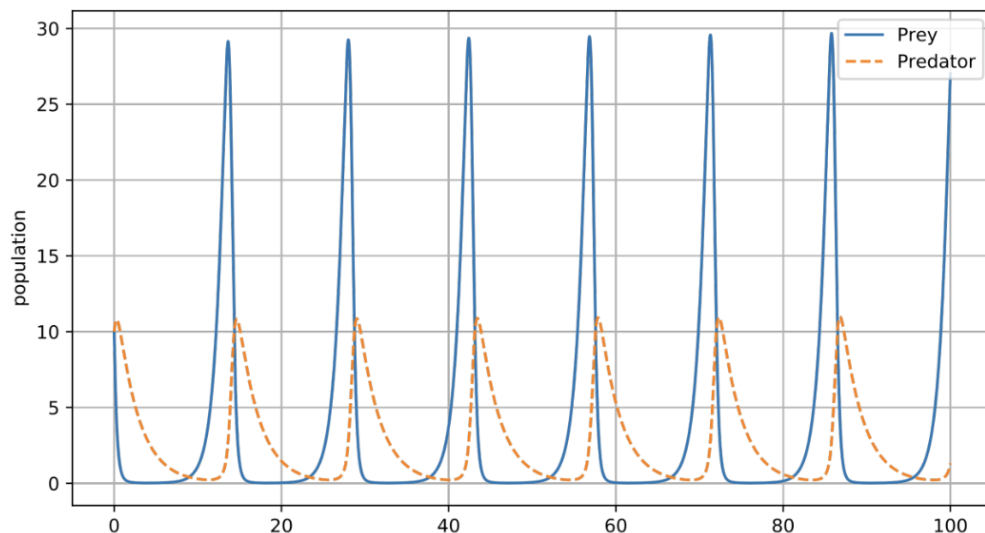
- A. Blocking chromoplast formation prevents carotenoid synthesis, so chloroplasts persist in the fruit and keep performing photosynthesis, fixing carbon into starch rather than pigment compounds.
- B. Failure of chromoplast differentiation eliminates vacuolar anthocyanin storage, forcing chloroplasts to store excess carbohydrates in the stroma.
- C. Leucoplast defects reduce mitochondrial ATP supply to roots, explaining their growth defects compared to shoots and leaves.

- D. Proplastids must differentiate into amyloplasts for starch storage in roots; if this pathway is disrupted, roots cannot accumulate starch needed for proper growth.
- E. Chromoplasts are responsible for regulating plasmodesmata aperture in fruit tissue, and without them, sugars that would normally be used for carotenoid production or translocation are instead rerouted into making starch granules, causing the tissue to build up starch rather than its normal product (pigments).

Solution: *A, Chromoplasts normally specialize in carotenoid accumulation (e.g., lycopene in tomato fruit). If chromoplast formation is blocked, plastids remain photosynthetic chloroplasts and channel carbon into starch rather than pigments. On the other hand, leucoplasts, especially amyloplasts, are key for starch storage and metabolic functions in roots; and without them, roots fail to grow properly. (B) Anthocyanin are vacuoles that store purple/blue pigments and they are not related to chromoplasts; (C) Leucoplast defects would not correlate with ATP production; (D) is plausible because proplastids do give rise to amyloplasts, but the defect in this case was specific to leucoplast, rather than a wholesale block of proplastid function; (E) wrongly attributes plasmodesmata regulation to plastids.*

Ecology (1 Question)

The graph below shows the population dynamics between a random groups of voles and hawks over time: (Note that hawks, shown in blue, have a broad range of prey; and voles, shown in red, depend on finite food resources, and may be subjugated to other environmental limits)



7. Which of the following best explains this prey and predator dynamic?

- A. Predator reproduction depends on prey abundance, so predator growth always lags until prey increase; in addition, predators are always fewer because they are limited by energy transfer efficiency between trophic levels.

- B. In prey-rich environments, predator mortality slows, but reproduction takes time, so predator peaks appear closer to prey peaks but still lag behind.
- C. Heavy predation pressure can temporarily reduce prey growth, giving the appearance that predator abundance rises sharply; however, predators cannot peak first or exceed prey numbers in the classical model.
- D. Predator and prey oscillations are independent, so the observed lag is random chance rather than a mechanistic result.
- E. Predator population size is capped by carrying capacity, whereas prey population has no such limit, resulting in a higher peak.

Solution: A, In the Lotka-Volterra framework, predator population growth is directly tied to prey availability. Prey must first increase, providing resources, then predator numbers rise afterward, causing the characteristic phase lag. (B) sounds plausible but overstates mortality changes — death rate is fixed in the model; (C) is tricky because predation does suppress prey, but predators cannot peak before prey under Lotka-Volterra dynamics; (D) is wrong since the cycles are coupled, not independent; (E) is incorrect since the classical model does not include carrying capacity.

Ethology (1 Question)

8. In a marine species, *Slinkus nopeii*, males exhibit two morphs: “guardians” which are larger and defend nesting sites; providing parental care and “sneakers,” smaller, non-territorial, and attempt to covertly fertilize eggs during spawning. Females exhibit minimal ornamentation and spawn selectively in nests of guardian males. Field data show that although sneaker males achieve fewer matings per season on average, their reproductive cost is minimal. Which of the following best explains the persistence of both male morphs of *Slinkus nopeii*?
- A. Sexual selection exclusively favors guardian males, but ecological drift allows for sneaker males to persist at low frequencies.
 - B. The sneaker morph is a product of post-copulatory selection, with sperm competition favoring less investment in parental care.
 - C. Frequency-dependent selection maintains both strategies, as the fitness payoff of each morph varies depending on relative abundance.
 - D. The presence of female choice for guardian males suggest that the sneaker strategy will eventually be eliminated through directional selection.
 - E. Guardian males demonstrate lower variance in reproductive success which balances out the overall population’s reproductive skew.

Solution: *C*, Guardians get most matings because females prefer their nests and they provide care, but sneakers pay much lower reproductive costs and can gain fertilizations opportunistically. When sneakers are rare, their strategy yields high relative fitness; if they become common their success falls. That negative frequency dependence produces a stable mix (an ESS) of both morphs.

Biosystematics (1 Question)

9. Ryan the red rhino has unfortunately lost his parents and is looking for a new home. However, he is unfortunately stuck in Antarctica. Using some ill-advised logic, you decide that Ryan would be most happy with foster parents of the closest related species present in a nearby zoo. Which of the following animals would be the best choice?

- A. Harry the horse
- B. Greg the gorilla
- C. Sandy the sandshrew
- D. Florence the fox
- E. Curie the camel

Solution: *A*, Rhinos are in the order Perissodactyla (odd-toed ungulates). Their closest living relatives are horses, zebras, and tapirs. Remember the acronym RED(Rhinos) HOT(Horse) TAKIZ(Tapirs and Zebras)

Part B (MTF): 3 Questions

11. In a commercial bedding-plant trial, a crop of *Arabidopsis thaliana* is split into 2 groups. One group is exposed to open sunlight (control), the other is placed under a mesh canopy (very shady). The researcher records (A) rapid hypocotyl and internode elongation, (B) auxin reporter signal (DR5) patterning, (C) cytokinin concentration in the shoot apical meristem, and (D) expression of genes in gibberellin (GA) biosynthesis. He hypothesizes that the shade avoidance response is triggered by light perception and involves changes in multiple plant hormones that limit growth to mainly stem elongation.
- I. In the canopy-shaded plants, auxin distribution increases toward the stem elongation zones, which is why longer hypocotyls are observed.
 - II. Cytokinin concentration in the shoot apical meristem is expected to increase under shade, promoting leaf expansion and lateral growth.

- III. Inactivation of phytochrome B under shady conditions would release transcription factors that promote elongation growth in shoots and roots.
- IV. Shade-induced elongation is partly supported by increased GA synthesis, which reduces DELLA-mediated repression of cell expansion.

Solution: I: True, Auxin biosynthesis and transport are stimulated in shade, and auxin accumulates in elongating regions of the hypocotyl and stem. II: False, Shade avoidance usually reduces cytokinin activity in the apical meristem, deprioritizing new leaf formation in favor of stem elongation. (Because this is what the inactive phytochrome signals to the plant: “I am in the shade of other plants – so if I don’t grow taller fast, I’ll lose the competition for sunlight.”) III: True, Under darkness, the low red light : far-red light ratio shifts phytochrome B from its Pfr form to its Pr form (inactive), lifting repression on PIFs (phytochrome-interacting factors) that drive elongation. IV: True, Shade promotes gibberellin biosynthesis and signaling, which degrade DELLA proteins (growth repressors), hence allowing elongation to proceed.

Researchers studying a putative cell-cycle regulator gene X delivered Cas9 and two independent guide RNAs (gRNA-A and gRNA-B) into some cultured mouse fibroblasts. Then they isolated clonal lines and sequence the target locus: some clones show frameshift indels, some show small in-frame deletions, and some are unedited at all. Western blots for X protein and proliferation assays were performed. To validate the results, they ran the same guides independently and tested rescue by re-expressing wild-type X. Which of the following is reasonable?

- I. Frameshifted clones are more likely to show complete loss of X protein on the Western blot than in-frame deletion clones.
- II. If a clone lacks detectable X protein, the observed phenotype (eg. slow proliferation) is likely due to nonsense-mediated mRNA decay rather than partial protein function.
- III. Cas9 introduces double-strand breaks that are repaired exclusively by homologous recombination.
- IV. Identical phenotypes across different gRNAs targeting X increase confidence that the phenotype is due to on-target effects rather than random off-target mutations.

Solution: I: True, Frameshifts typically introduce premature stop codons leading to truncated proteins and/or nonsense-mediated mRNA decay (NMD), so protein is often absent. In-frame deletions, on the other hand, preserve the reading frame so most of the time, a valid (possibly functional), shorter protein may still be produced. II: True, Absence of protein suggests complete loss of translation or rapid degradation (often from NMD or unstable truncated protein). A phenotype in such a clone is therefore more plausibly explained by loss-of-function rather than by residual/partial protein activity (which would require detectable protein in the first place). III: False, The predominant repair pathway for Cas9 DSBs in

most somatic cells is non-homologous end joining (NHEJ), which yields indels. Homology-directed repair (HDR) can also occur but usually at lower frequency and typically requires a donor template and cells in S/G2. IV: False, Independent guides producing the same phenotype argue against a single random off-target event causing the effect. (Caveat: shared off-targets or clonal variation are possible, so additional controls like rescue with wild-type *X* are still needed.)

An endocrinology lab in NYC aims to study how moderate caloric restriction (15–20% below average recommended consumption) affects gametogenesis in adult mice over 12 weeks. Surprisingly, female mice showed irregular estrous cycles and delayed ovulations; while males showed shrunken testis and lower epididymal sperm counts. The team then measured the circulating LH/FSH levels, follicle counts, spermatogenic staging, apoptotic markers, and calcium-mediated egg activation in vitro. Which of the following properly describes gametogenesis under nutritional stress?

- I. In females, caloric restriction may prolong the arrest of primary oocytes in prophase I by suppressing gonadotropin release.
- II. Each spermatocyte II normally yields two functional sperm cells, but caloric restriction increases apoptosis during spermiogenesis, which is why there's reduced sperm count in male mice.
- III. Fertilization in mammals triggers completion of meiosis II in secondary oocytes, a process dependent on calcium oscillations induced by sperm entry.
- IV. Unlike spermatogenesis, which proceeds continuously from puberty onward, oogenesis involves long meiotic arrests that make it particularly sensitive to systemic stressors.

Solution: I: True, Lack of nutrition lowers GnRH, which in turn reduces LH and FSH; and without gonadotropin stimulation, follicles could not resume meiosis, so many oocytes are arrested in the long prophase I. II: True, Secondary spermatocytes undergo one meiotic division to make two haploid spermatids (which will eventually differentiate into sperm). However, systemic stress like calorie-deficit can trigger germ-cell apoptosis during later stages like spermiogenesis/elongation, thus lowering final sperm numbers. III: True, Sperm entry induces intracellular Ca²⁺ oscillations in the oocyte that cause exit from metaphase II and completion of meiosis, producing the haploid ovum and a second polar body. IV: True, Oogenesis has prolonged arrests (prophase I for years and metaphase II until fertilization), so hormonal and energetic disruptions more readily interfere with follicle maturation and meiotic resumption than with the case of continuous spermatogenesis.