

USABO Semifinal Exam - Answer Key

June 24, 2020

100 questions, 150 points

90 minutes

Animal Anatomy and Physiology (25 questions, 37.5 points)

Cell Biology (20 questions, 30 points)

Genetics and Evolution (20 questions, 30 points)

Plant Anatomy and Physiology (15 questions, 22.5 points)

Ecology (10 questions, 15 points)

Ethology (5 questions, 7.5 points)

Biosystematics (5 questions, 7.5 points)

Instructions:

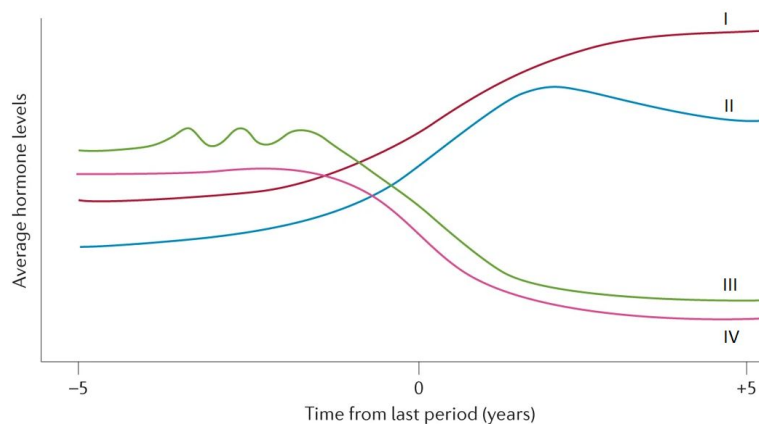
Do not start until instructed to do so by your proctor. Please put away your books and other materials. Clear your desk of all but the following items: photo ID, number 2 pencil, scratch paper, non-programmable calculator (optional).

The exam consists of 100 multiple choice questions, totaling 150 points, to be completed in 90 minutes. Questions are worth either 1 point, 1.5 points, or 2 points; the point value of each question is indicated next to the question number. Questions asking for a single answer state "Select ONE" while questions which may have more than one answer state "Select ALL that apply". Questions which may have more than one answer will receive 1.0/0.7/0.2/0/0/0, relative to the question's total point value, for 5/4/3/2/1/0 options correctly selected, respectively.

Animal Anatomy and Physiology

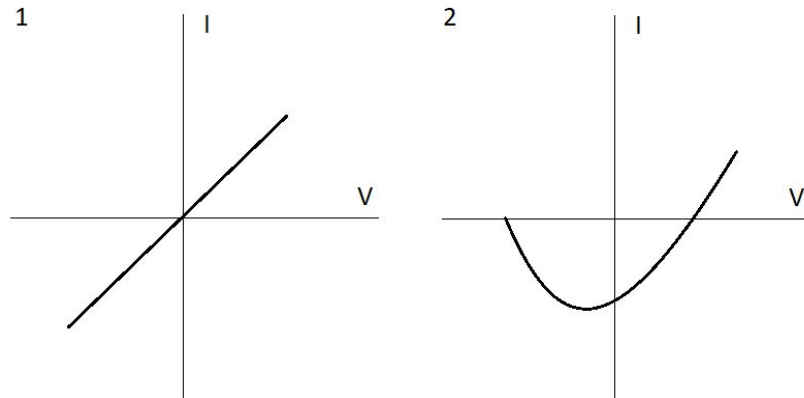
25 questions, 37.5 points

1. [1.5 pts] With the onset of menopause, ovarian follicles gradually stop releasing eggs. A corresponding change in reproductive hormone levels occurs. The figure shows the changes in estradiol, FSH, hormone X, and LH during this pre- to post-menopausal transition. Hormone X is a marker for developing follicles. Which choice correctly labels the four hormones? Select ONE.



- a. I - Estradiol; II - Hormone X; III - FSH; IV - LH
- b. I - FSH; II - LH; III - Estradiol; IV - Hormone X**
- c. I - FSH; II - Estradiol; III - LH; IV - Hormone X
- d. I - Hormone X; II - LH; III - Estradiol; IV - FSH
- e. I - Estradiol; II - Hormone X; III - LH; IV - FSH

2. [2 pts] You use voltage clamp to measure the current (I) at different voltages (V) of two membrane ion channels, channels 1 and 2, plotted in the figures below.



In addition to current and voltage, you define two more characteristics:

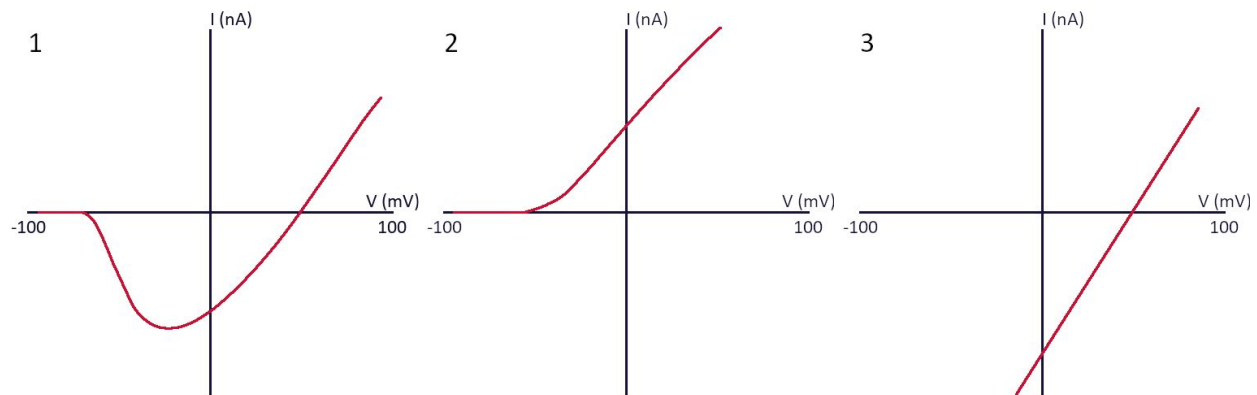
Equilibrium point: Voltage at which no ions flow

Conductance: Change in current per change in voltage

Which of the following statements about the two channels is accurate? Select ONE.

- a. Both channels have one equilibrium point when the voltage is 0
- b. The maximal current of channel 1 is smaller than the maximal current of channel 2
- c. The voltage of channel 1 changes faster than the voltage in channel 2
- d. The conductance of channel 1 does not change with voltage while that of channel 2 does
- e. Channel 1 is monomeric while channel 2 is dimeric

3. [2 pts] Below are current-voltage graphs of three different ion channels, plotting ion current (I) as a function of membrane potential (V). Note that outward current is measured.



Which of the following choices best matches the current-voltage graphs to the corresponding ion channel? Select ONE.

- 1: voltage-gated potassium channel; 2: voltage-gated sodium channel; 3: sodium pore channel (not gated)
 - 1: voltage-gated sodium channel; 2: voltage-gated potassium channel; 3: chloride pore channel (not gated)
 - 1: voltage-gated potassium channel; 2: potassium pore channel (not gated); 3: chloride pore channel (not gated)
 - 1: voltage-gated sodium channel; 2: voltage-gated potassium channel; 3: sodium pore channel (not gated)
 - 1: sodium pore channel (not gated); 2: potassium pore channel (not gated); 3: voltage-gated sodium channel
4. [1.5 pts] You discover a new drug affecting the digestive system. Upon characterization, you discover that it inhibits H^+/K^+ ATPase and increases mucin secretion in the stomach. Its half life is 75 minutes and is easily absorbed by the body. Which of the following is true after taking the drug? Select ONE.
- The blood after passing through the stomach will have a higher pH than before
 - The change in K^+ concentration will cause increased stomach muscle contractions
 - The stomach will become more vulnerable to enzymatic damage
 - The drug will be ineffective against gastric ulcers (stomach lining sores)
 - The drug will be ineffective for nighttime use

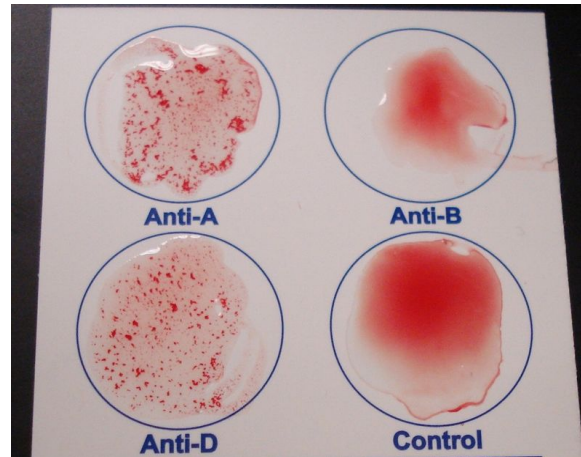
5. [1.5 pts] In animal development, several specialized groups of cells are involved in guiding cell fate. One such fictitious region, Frame's organizer, is involved in the decision of cells to become either liver or heart cells. In a wild-type gastrula, all undifferentiated cells express the JAIN receptor. Binding of the BHV ligand to this receptor induces differentiation into a liver cell. Undifferentiated cells that do not bind the BHV ligand with this receptor will become heart cells.

BHV secretion is high throughout the gastrula. However, Frame's organizer is located on the dorsal side of the gastrula and secretes ligand traps that sequester the BHV ligand, preventing binding to the JAIN receptor.

Animal A has a mutation in the JAIN receptor such that it can no longer bind to BHV. Animal B has the same JAIN receptor mutation, but in addition, its Frame's organizer is non-functional, and does not secrete ligand traps. Which one of the following statements is true about the fates of cells in Animal A and Animal B? Select ONE.

- a. Animal A will develop heart cells on both dorsal and ventral sides. Animal B will develop heart cells on both dorsal and ventral sides.
- b. Animal A will develop heart cells on the dorsal side and liver cells on the ventral side. Animal B will develop heart cells on both dorsal and ventral sides.
- c. Animal A will develop heart cells on both dorsal and ventral sides. Animal A will develop heart cells on the dorsal side and liver cells on the ventral side.
- d. Animal A will develop liver cells on both dorsal and ventral sides. Animal B will develop liver cells on both dorsal and ventral sides.
- e. Animal A will develop heart cells on the dorsal side and liver cells on the ventral side. Animal B will develop liver cells on both dorsal and ventral sides.

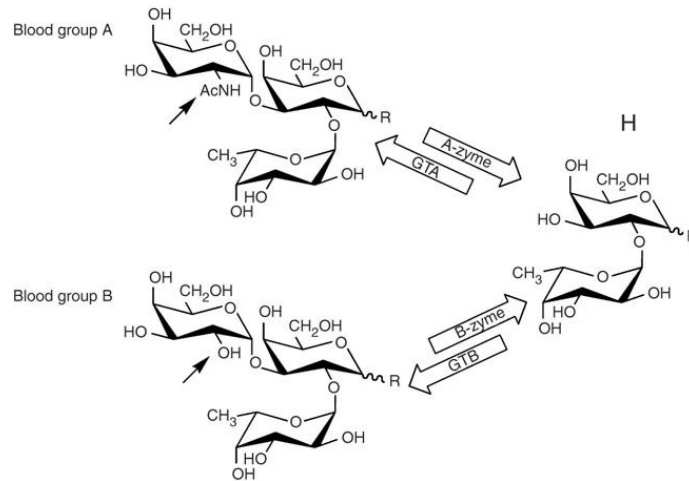
6. [1 pt] Much care must be put into blood transfusions due to the potential complications involved with antibodies in the recipient's blood attacking antigens found in the donor blood. You wish to determine the blood type of one of your patients, so you take a blood sample and mix with anti-A, anti-B, and anti-D antibodies (D antigen is the Rh factor). You also mix the blood sample with a negative control antibody ("control").



What is your patient's blood type? Select ONE.

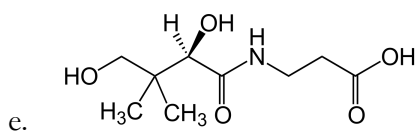
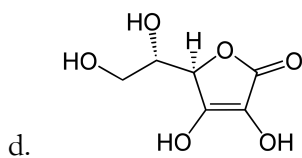
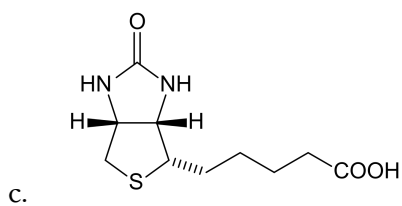
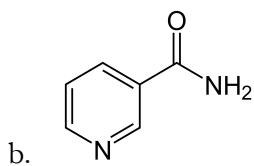
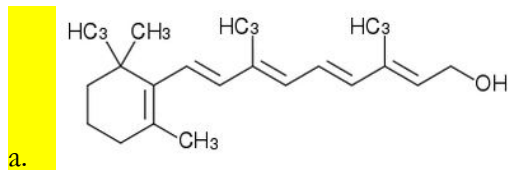
- a. A negative
- b. A positive
- c. B positive
- d. AB negative
- e. O negative

7. [1.5 pts] To solve incompatibilities in blood transfusions, you have formulated the enzymes A-zyme and B-zyme depicted in the picture below that are able to cleave a portion of the A and B antigen to match that of an H antigen (the antigen present in blood type O). You've heard that type O blood is the "universal donor", so you hypothesize that you can use your enzymes to convert all donated blood to type O, solving the problem of compatibility in blood transfusions. Which of the following is/are true about this idea? Select ALL that apply.

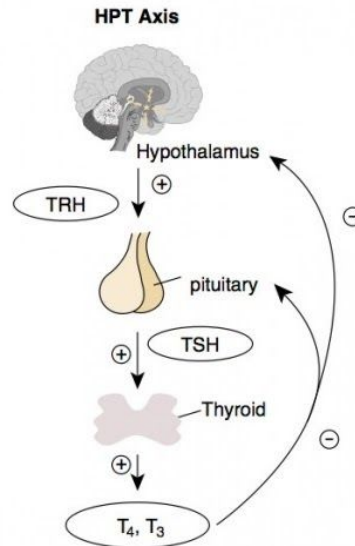


- Your idea will not succeed as cleaving these glycoproteins reduces the RBCs ability to carry oxygen.
- Your idea will not succeed because some A and B antibodies can still distinguish between epitopes not depicted in the diagram.
- Your idea will not succeed because antibodies in the donor blood can still attack antigens present in the recipient's body, leading to a significant effect on the success of the transfusion .
- Your idea could succeed as long as the MHC I molecules on the donor RBCs can still be recognized by the recipient's cytotoxic T cells.
- Your idea could succeed as long as the Rh factors of donor and recipient are compatible

8. [1 pt] Uh oh spaghetti! You have overdosed on gummy vitamins and died. Which of the following vitamins was the most likely culprit of your overdose? Select ONE.



9. [1.5 pts] You are a doctor working with a patient who has come in complaining of fatigue. Although it is the middle of summer, you notice your patient is wearing a heavy winter coat and sweatpants. Looking at their medical history, you also notice that their weight from their checkup a few months ago has gone from 163 lbs to 204 lbs. You suspect that it has something to do with their HPT (Hypothalamus-Pituitary-Thyroid) axis. Which of the following could explain their symptoms? Select ALL that apply.



- a. Iodine surplus
- b. Selenium deficiency
- c. Overexpression of TRH
- d. Production of autoantibodies blocking the TSH receptor
- e. Lesion compressing the posterior pituitary

10. [1.5 pts] You are interested in studying the genetic basis of organ formation and decide to use chicken eggs as a model system. You choose 3 homeotic genes; transcription of gene A is required for ectoderm formation, transcription of B is required for endoderm formation, and transcription of gene C directs mesoderm formation. You expose chicken embryos to OxyClean and find that gene A is mutated and nonfunctional across all of the embryos. The genes regulate one another in the following fashion: gene A blocks expression of genes B and C, and gene C blocks expression of gene B. Note that in untreated embryos, all organs develop normally. Which organs could develop within the embryo? Select ALL that apply.

- a. Epidermis
- b. Thyroid
- c. Stomach
- d. Heart
- e. Brain

11. [1.5 pts] A patient, feeling regularly lightheaded and dizzy for several weeks, sees a cardiac specialist, who discovers that the symptoms arise from dysfunction in a region of the heart that electrically connects ventricular and atrial muscle tissue. This region is so damaged that ventricles electrically respond to atria only around half the time in the patient's heart.

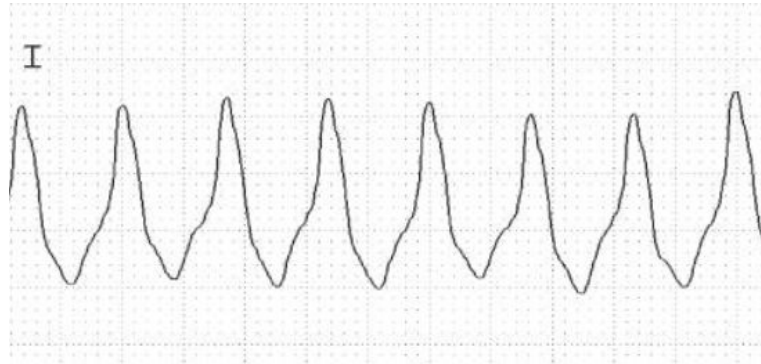


Using the information given and ECG above from a healthy person, which of the following ECGs most likely belongs to the patient? Select ONE.



- e. None of these ECGs could belong to the patient.

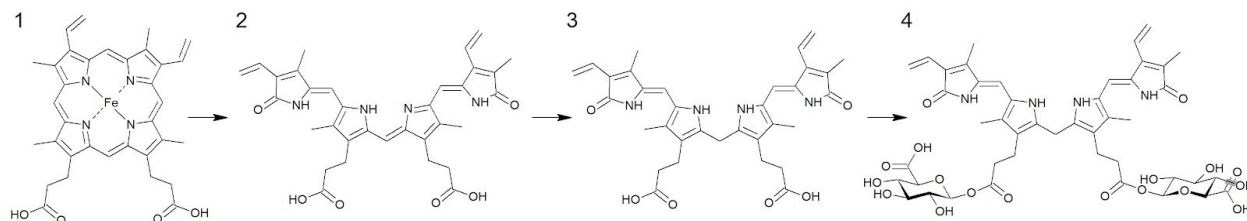
12. [2 pts] Your patient has heart problems, so you decide to obtain an ECG. You show the ECG to your cardiologist friend, who notes the short RR interval and abnormally wide QRS complex. She reminds you that the bundle branches and Purkinje fibers conduct electrical impulses much faster than cardiomyocytes do.



Which of the following best explains your patient's heart problem? Select ONE.

- a. SA node rate is too high, leading to sinus tachycardia
 - b. AV node functions as pacemaker due to SA node dysfunction, leading to junctional rhythm
 - c. Ventricular cardiomyocytes trigger heartbeats at a high rate, leading to ventricular tachycardia
 - d. AV node triggers heartbeats at a high rate, leading to junctional tachycardia
 - e. Atrial flutter triggers fast ventricular contraction, leading to supraventricular tachycardia
13. [1.5 pts] Which of the following drugs would lead to a decrease in blood pressure? Select ALL that apply.
- a. An antagonist of vasopressin receptors
 - b. An antagonist of aldosterone receptors
 - c. An antagonist of β_1 -adrenergic receptors
 - d. An antagonist of calcium channels in arterial smooth muscle
 - e. An agonist of mechanoreceptors involved in the carotid baroreceptor reflex

14. [2 pts] The liver is responsible for processing and excreting many toxic waste products. One such pathway is shown below. Elsewhere in the body, compound 1 is processed into compound 3, which is transported to the liver. In the liver, compound 3 is conjugated to glucuronic acid to produce compound 4, which is excreted in bile.

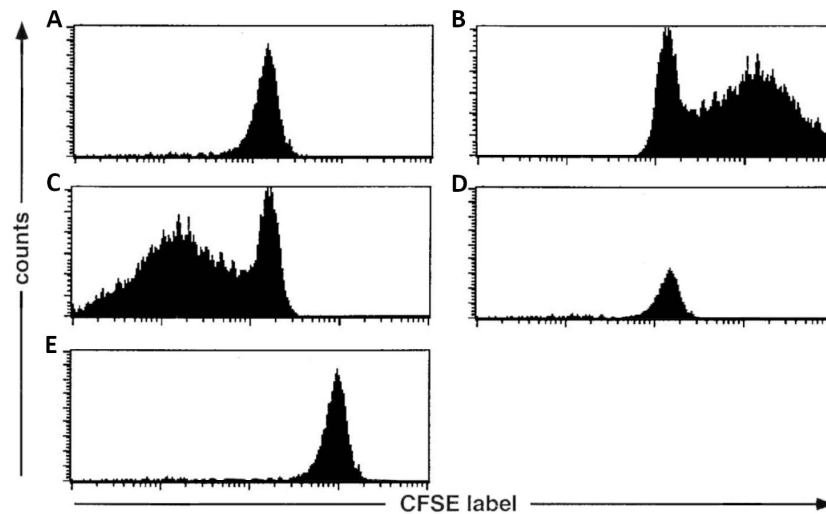


A complete metabolic panel of one of your patients reveals that he has highly elevated levels of compound 3 in his blood, but levels of compound 4 are only slightly elevated. Based on this information, which of the following may be the cause of this abnormality? Select ALL that apply.

- Blockage of the common bile duct by a gallstone
 - Destruction of erythroblasts due to anti-erythroblast auto-antibodies
 - Defects in ABCC2, the organic anion transporter at the canalicular surface of hepatocytes
 - Defects in UDP-glucuronosyltransferase
 - Chronic hepatitis B infection
15. [1.5 pts] Which of the following drugs would directly result in flaccid muscle paralysis (absence of contractile activity)? Select ALL that apply.
- An antagonist of acetylcholine receptors
 - An inhibitor of acetylcholinesterase
 - An enzyme that breaks down SNARE complex proteins in axon terminals
 - A drug that increases the permeability of the sarcoplasmic reticulum to Ca^{2+}
 - An inhibitor of the plasma membrane sodium-calcium antiporter

Questions 16-17 are about the antigen cross-presentation ability of dendritic cells.

16. [1.5 pts] Dendritic cells (DCs) are unique in being able to cross-present antigens, a process where extracellular antigens are presented on class I MHC. To study them, you inject wild-type mice with transgenic $CD8^+$ T cells expressing TCR against an antigen derived from *Listeria monocytogenes*, an intracellular bacterium which infects endothelial cells. Before injection, these T cells are chemically labeled on the cell surface with CFSE, a fluorescent dye. After T cell transfer, you inject the mice with *L. monocytogenes*, re-isolate the $CD8^+$ T cells from the spleens of the infected mice, and assess $CD8^+$ T cell proliferation by the dilution of the CFSE dye.



Panel A shows results from wild-type mice that were not infected with *Listeria*. Which of the panels is most likely to show results from wild-type mice that were infected with *Listeria*? Select ONE.

- a. Panel A
- b. Panel B
- c. Panel C
- d. Panel D
- e. Panel E

17. [2 pts] Next, you repeat the experiment with DC-deficient mice. Unfortunately, these results got lost. Which of the following choices correctly explains the expected results from DC-deficient mice? Select ONE.

- a. Results from uninfected mice resemble panel B since the antigen is not present to stimulate proliferation
- b. Uninfected and *Listeria*-infected mice show the same results since only DCs can present extracellular *Listeria* antigen on MHC-I to naive CD8⁺ T cells
- c. Results from *Listeria*-infected mice resemble panel C since DCs are required to activate naive CD8⁺ T cells via MHC-I
- d. Uninfected and *Listeria*-infected mice show different results since only DCs can present extracellular *Listeria* antigens on MHC-II
- e. Results from *Listeria*-infected mice resemble panel D since infected endothelial cells can present *Listeria* antigen to CD4⁺ T cells via MHC-II

18. [1 pt] You fall into the Charles river and are unable to swim back to shore! As you drown, which of the following will occur? Select ALL that apply.

- a. You become hypoxemic.
- b. Your blood pH will increase.
- c. Your plasma concentration of bicarbonate will increase.
- d. Your plasma concentration of chloride will increase.
- e. Your plasma concentration of lactic acid will increase.

19. [2 pts] Creatinine is a breakdown product of creatine phosphate in muscle; typically, creatinine is produced at a constant rate. Because creatinine is freely filtered by the kidney and not reabsorbed (though some is secreted in the proximal convoluted tubule), creatinine is often used as a marker of renal function. One of your patients has a serum creatinine concentration of 1.6 mg/dL (normal 0.7–1.3 mg/dL); over 24 hours, he produced 1.5 L of urine with a urine creatinine concentration of 85 mg/dL. For reference, a normal GFR is ≥ 90 mL/min. Which of the following is/are true about creatinine as an indicator of renal function? Select ALL that apply.

- a. Elevated serum creatinine could be the result of reduced GFR from kidney disease.
- b. Elevated serum creatinine could be the result of muscle damage.
- c. The patient's GFR is lower than expected from normal kidney function.
- d. The calculated creatinine clearance from urine concentration underestimates GFR due to proximal convoluted tubule secretion of creatinine.
- e. The patient's symptoms could be due to volume depletion, such as from hemorrhage or dehydration.

20. [1.5 pts] Diabetic ketoacidosis (DKA) is a complication seen in diabetics, often characterized by hyperglycemia (high blood glucose levels), excess ketone bodies in the blood, and acidosis. Which of the following is/are true about DKA? Select ALL that apply.

- a. Presence of glycosuria (glucose in urine) suggests that the sodium-glucose transporters in the nephron are not saturable.
- b. Low insulin levels can lead to reduced gluconeogenesis in the liver, illustrating a negative feedback mechanism of the body to mitigate the effects of DKA.
- c. Glucosuria can cause polyuria (production of large volumes of urine) via osmosis, leading to severe dehydration, and eventual hypovolemic shock.
- d. Hypoventilation is a common symptom of DKA, hence a DKA patient should be administered epinephrine as a first line of treatment.
- e. DKA is more likely to occur in Type 2 diabetics.

21. [1.5 pts] A patent foramen ovale (PFO) is a common condition seen in newborns which involves a connection between the atria that abnormally stays open after birth. Which of the following statements accurately describe(s) the foramen ovale and PFO? Select ALL that apply.

- a. The atria are connected in fetuses because the heart is not used for circulation; the liver takes over the circulatory function of the heart to give the heart the maximum time it can in order to fully develop.
- b. Closure of the foramen ovale at birth in normal babies is due to a sudden increase in blood passing through the superior vena cava, resulting in increased right atrial pressure compared to the left, leading to closure of the foramen ovale.
- c. In suspected PFO patients, a bubble test may be performed to verify the diagnosis. This involves injecting a saline solution with some bubbles into a vein. Rapid appearance of bubbles in the left atrium suggests that the patient does not have PFO.
- d. In hypoxic conditions, PFO patients have an advantage over normal people due to improved delivery of oxygenated blood to the left atrium.
- e. PFO patients are likely to be at higher risk of getting a stroke.

22. [1.5 pts] Observe the sample below, shown at a magnification of 90X.

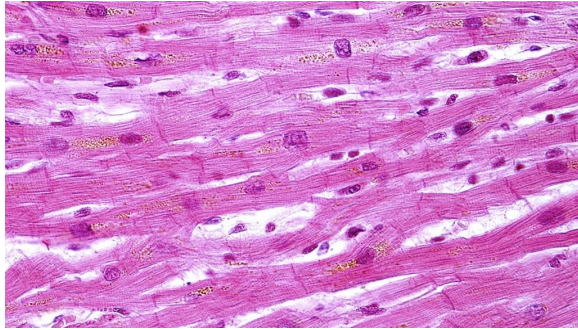


Which of the following is a biological function of the structure circled in red? Select ONE.

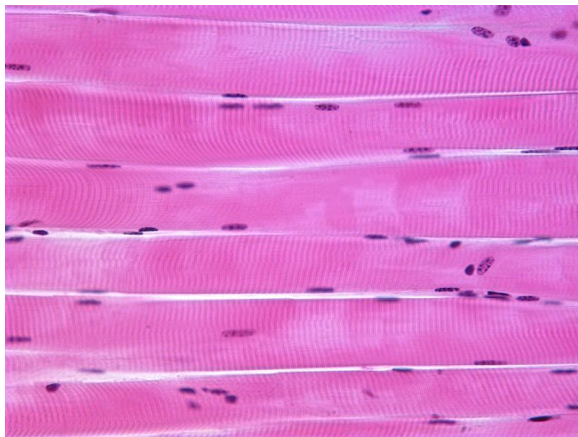
- a. Signals changes in the body's rotational acceleration to the brain, a key component of proprioception.
- b. Produces vasopressin, a hormone involved in renal water regulation.
- c. Secretes and reabsorbs filtrate to regulate blood pressure and waste removal.
- d. Promotes blood flow by acting as a pressure reservoir during diastole.
- e. Prevents bile from entering the small intestine when active digestion is not occurring.

Questions 23-25: Histology! Match the histological sections (A-E) with its appropriate name. Not all of the pictures will be used.

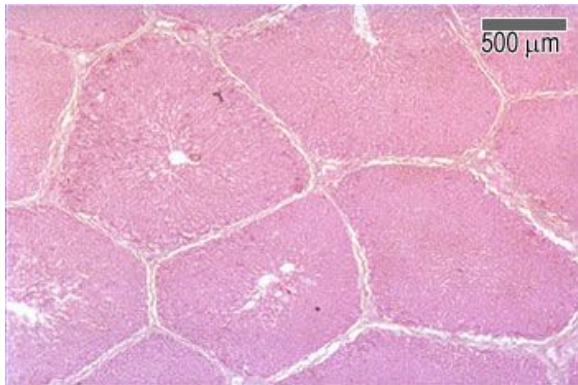
A.



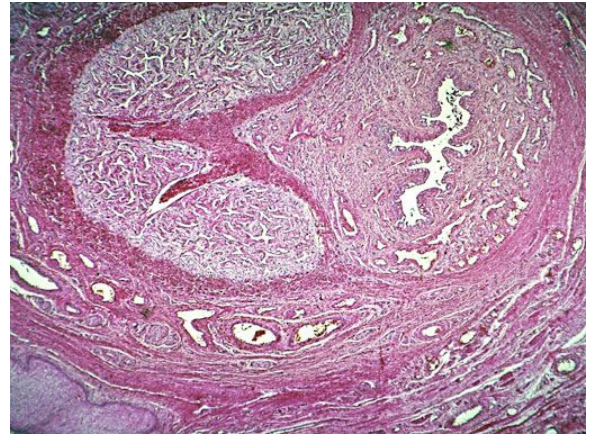
B.



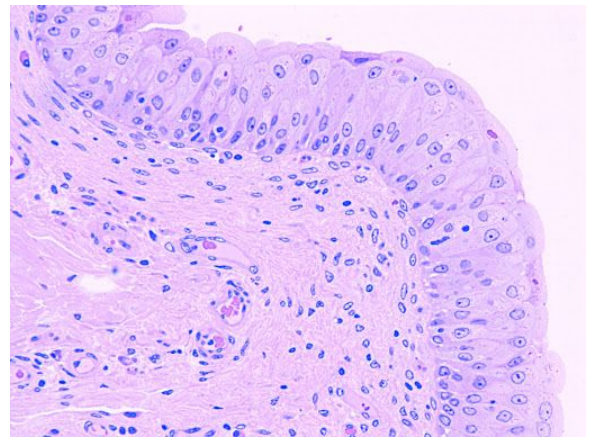
C.



D.



E.



23. [1 pt] Liver. Select ONE.

- a. A
- b. B
- c. C

- d. D
- e. E

24. [1 pt] Cardiac muscle. Select ONE.

- a. A
- b. B
- c. C

- d. D
- e. E

25. [1 pt] Bladder. Select ONE.

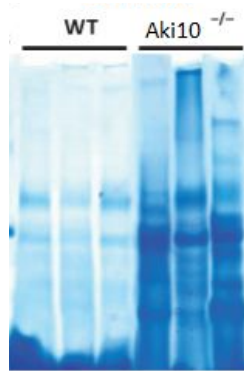
- a. A
- b. B
- c. C

- d. D
- e. E

Cell Biology

20 questions, 30 points

26. [1 pt] Aki10 is a gene of unknown function in mice associated with acute kidney injury. You decide to generate Aki10 knockout mice (Aki10^{-/-}) and collect their urine, which you run on an SDS-PAGE gel followed by Coomassie staining to visualize proteins. The left three lanes are samples from wildtype mice while the right three lanes are samples from Aki10^{-/-} mice.

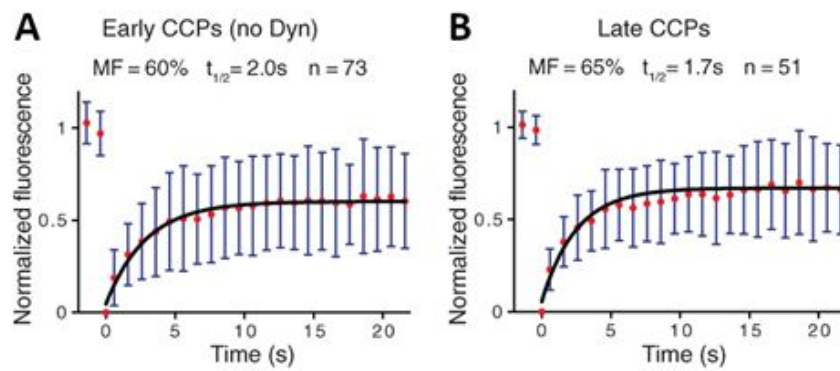


Based on this information, which of the following is the most likely subcellular localization of Aki10 protein? Select ONE.

- a. Nucleus
- b. Plasma membrane
- c. Endoplasmic reticulum
- d. Mitochondria
- e. Golgi apparatus

Questions 27-28 are about clathrin kinetics during endocytosis.

27. [1 pt] Clathrin is a protein that plays a key role in endocytosis—first by forming clathrin-coated pits (CCPs) on the plasma membrane, then by forming clathrin-coated vesicles (CCVs). To study the kinetics of clathrin exchange on CCPs, you perform a fluorescence recovery after photobleaching (FRAP) experiment. Briefly, clathrin light chain A (CLTA) was tagged with red fluorescent protein (RFP) and expressed; then, a focused laser was used to photobleach RFP at either an early CCP or a late CCP; finally, the amount of RFP fluorescence was measured for 20 seconds after photobleaching. Panel A presents FRAP data for early CCPs, while panel B presents FRAP data for late CCPs.



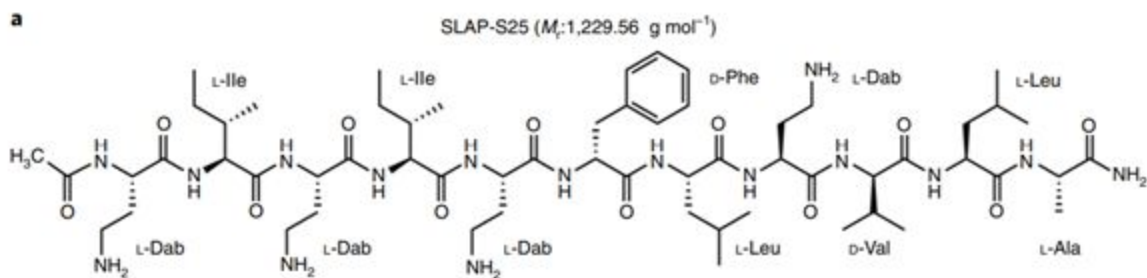
Which of the following statements about the FRAP data shown in panel A is/are true? Select ALL that apply.

- a. At 0 seconds, fluorescence was 1 because fluorescence values are normalized relative to the initial fluorescence value.
- b. At 0 seconds, fluorescence was 0 because the photobleaching laser eliminated all fluorescence at the early CCP.
- c. Between 0 and 20 seconds, fluorescence decreased as photobleached CTLA-RFP molecules gradually lost fluorescence.
- d. Between 0 and 20 seconds, fluorescence increased as photobleached CTLA-RFP molecules chemically regained fluorescence.
- e. Between 0 and 20 seconds, fluorescence increased as photobleached CTLA-RFP molecules were replaced by non-photobleached molecules.

28. [2 pts] Based on the results of your FRAP experiment, which of the following statements about CCP formation is/are consistent with the provided data? Select ALL that apply.

- a. Clathrin binds coated pits strongly and does not dissociate at a significant rate.
- b. Clathrin molecules coating CCPs all demonstrate rapid exchange with the free cytosolic clathrin pool.
- c. Approximately 40% of CCP clathrin molecules associate strongly with adaptor membrane proteins while the remaining 60% are free to unbind.
- d. Early CCPs show greater clathrin exchange than late CCPs, consistent with a maturation model where the clathrin coat becomes increasingly rigid.
- e. The rapid clathrin exchange kinetics in both early and late CCPs argue against a model where clathrin geometry changes after initial coat formation.

29. [1.5 pts] Your friend Jasba is studying potential antibiotic adjuvants, and he stumbles upon a molecule called SLAP-S25. The structure of SLAP-S25 is shown below.



What is the charge on SLAP-S25 at pH 7? Select ONE.

- a. -1
- b. 0
- c. 2
- d. 4
- e. 5

30. [1 pt] You obtain a mystery drug on the street, which you add to the adrenal cortex cells that you've been culturing. To your surprise, you find that aldosterone and cortisol synthesis is greatly inhibited. Where could this mystery drug be acting? Select ALL that apply.

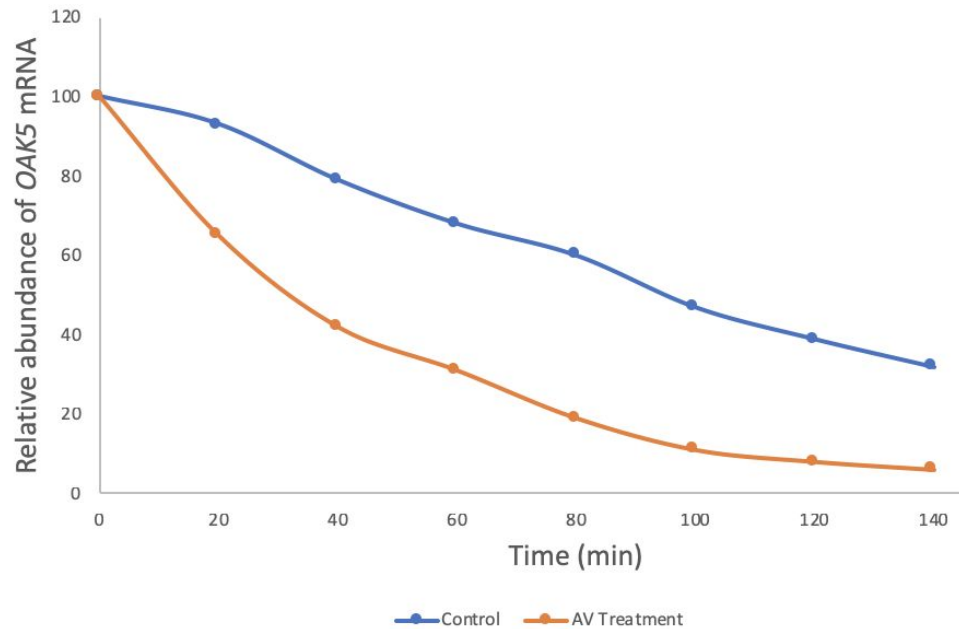
- a. Mitochondria
- b. Rough Endoplasmic Reticulum
- c. Smooth Endoplasmic Reticulum
- d. Peroxisome
- e. Golgi Apparatus

Questions 31-32 are about an experiment to determine the effects of a virus on an mRNA.

31. [2 pts] You have discovered a new virus, known as Atharvovirus (AV), that is spreading in populations of mice and is capable of causing death within 24 hours. You find that in mouse cells, total mRNA levels of the essential protein-coding gene OAK5 drop by >90% within the first few hours of AV infection. Intrigued, you perform a follow-up experiment, where you briefly add labeled NTPs into the cells to let them be incorporated into OAK5 mRNA until steady state. Then, you dilute the labeled NTPs with an excess of unlabeled NTPs, and at the same time, treat cells with either AV or a mock control. You then isolate RNA from the cells, isolate the labeled RNA fraction, and perform RT-qPCR to quantify the levels of labeled OAK5 mRNA in cells. Which of the following is/are true about your experiment? Select ALL that apply.

- a. For this experiment, you could use radioactive ^{32}P labeling of NTPs on the gamma phosphate to quantify OAK5 mRNA levels, with radioimmune blotting before quantification
- b. For this experiment, you could pulse 4-thiouracil into the growth media, and then use affinity column pulldown for the thiouracil label, followed by RT-qPCR to quantify OAK5 mRNA levels
- c. This experiment will let you determine if accelerated mRNA decay plays a role in the drop in OAK5 mRNA levels
- d. This experiment will NOT let you determine if accelerated mRNA decay plays a role in the drop in OAK5 mRNA levels
- e. Instead of RT-qPCR, you could use Northern blotting to quantify the levels of the labeled OAK5 mRNA

32. [1.5 pts] Below is a graph depicting the data that you have collected from this experiment. Which of the following is/are true about your findings? Select ALL that apply.



- a. The half-life of the OAK5 mRNA is unchanged by treatment with AV.
- b. The half-life of the OAK5 mRNA is decreased by a factor of 3 by treatment with AV.
- c. These data are consistent with a model in which AV binds the promoter upstream of the OAK5 gene and inhibits its transcription into mRNA, but does NOT alter the stability of the OAK5 mRNA.
- d. These data are consistent with a model in which AV destabilizes OAK5 mRNA by inducing its deadenylation, accelerating its decay.
- e. These data are consistent with a model in which AV destabilizes OAK5 mRNA by inducing its adenylation, accelerating its decay.

33. [1.5 pts] You have discovered a broad-spectrum antibiotic that can kill both gram-negative and gram-positive bacteria. From previous analyses, you know that the antibiotic binds and inhibits an essential bacterial enzyme. Which of the following statements is/are true? Select ALL that apply.
- a. In gram-positive bacteria, the antibiotic could permeate through the outer membrane and inhibit peptidyl transferase activity in the large ribosomal subunit.
 - b. In cellular lysate, the thermal stability of the bacterial enzyme would increase upon antibiotic introduction.
 - c. If the thermal stability of the enzyme in the intact cell treated with antibiotic is identical to that of the cellular lysate treated with antibiotic, then we can deduce that the antibiotic is able to enter the cell.
 - d. If the antibiotic primarily operates by inhibiting peptidoglycan cross-linkage enzymes, it will be especially effective in gram-negative bacteria versus gram-positive bacteria.
 - e. The antibiotic could inhibit tubulin polymerization during bacterial cell division.
34. [2 pts] You are studying an enzyme and wish to understand its mechanism. Your friend, a structural biologist, has crystallized the enzyme and solved its structure. Noticing that the enzyme has a large hydrophobic pocket, she identified four residues which may play a role in catalysis: Lys42, Leu105, Asp175, and Ser351. Which of the following is/are true about these four residues and their potential role in catalysis? Select ALL that apply.
- a. The pKa of Lys42 is lower than the pKa of free lysine dissolved in water.
 - b. The location of Lys42 in the hydrophobic pocket increases its reactivity.
 - c. Leu105 is likely involved in the catalytic mechanism of the enzyme.
 - d. The pKa of Asp175 is lower than the pKa of free aspartic acid dissolved in water.
 - e. Ser351 could serve as a proton donor in acid-base catalysis.

35. [1 pt] The nucleus is a structurally complex organelle in the cell, consisting of a nuclear envelope, matrix (which includes the nuclear lamina), and nucleoplasm. Which of the following statements are true? Select ALL that apply.

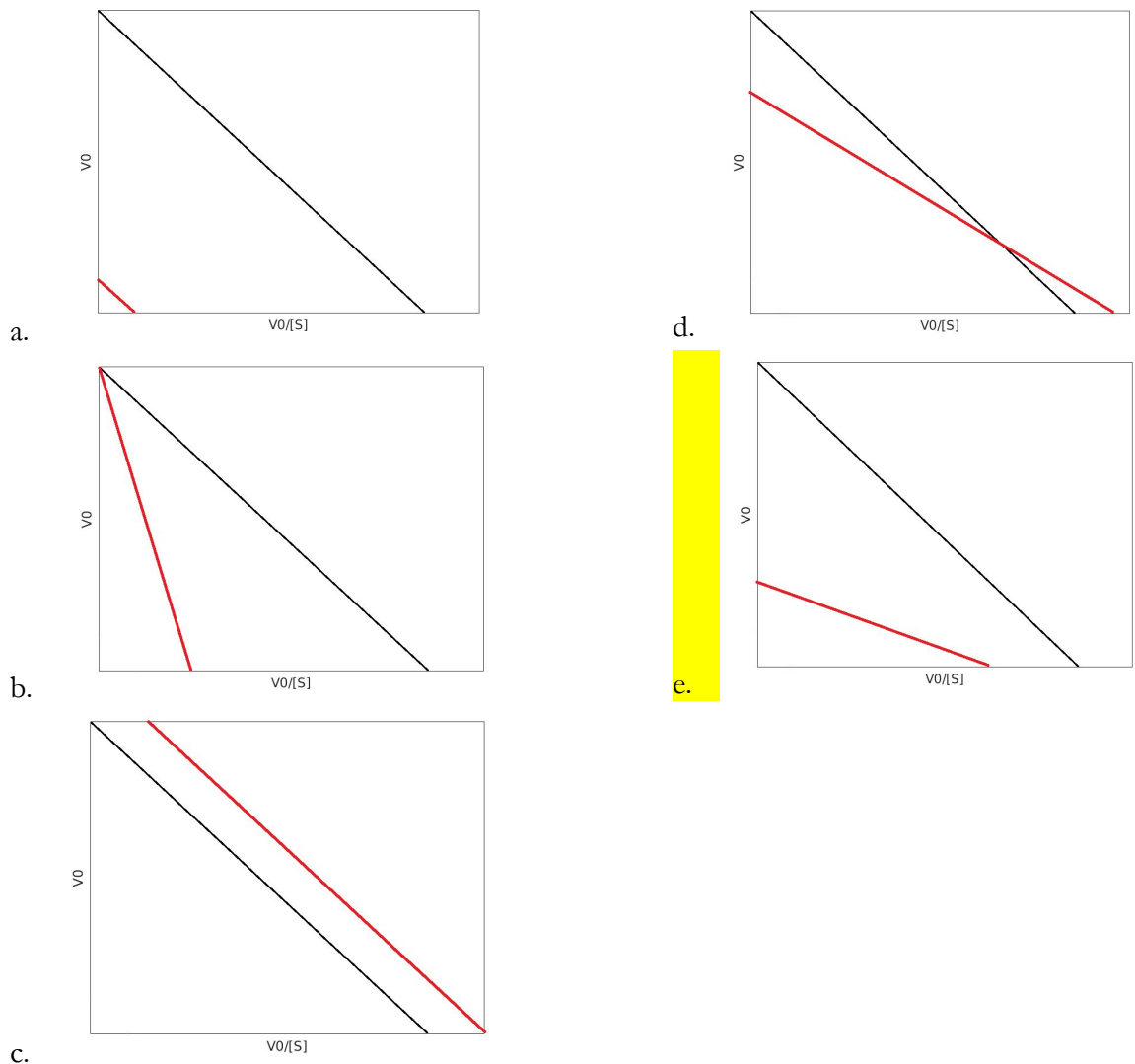
- a. The nuclear membrane and lamina depolymerize upon phosphorylation of Cdk1.
- b. The nuclear lamina is largely composed of microtubules and microfilaments.
- c. The nuclear pore complexes (NPCs) spanning the nuclear membrane allow the passage of RNA and ribosomal proteins from the nucleus to the cytoplasm.
- d. The outer nuclear membrane is continuous with the membrane of the smooth endoplasmic reticulum (SER).
- e. Nuclear accessory genes encoding proteins involved in formation of the spindle apparatus may exhibit differential exon splicing in germ cells compared to somatic cells.

36. [1.5 pts] You are investigating a mutation in pancreatic lipase in which Asp is replaced with Ala in the active site, resulting in a lower binding affinity for Ca^{2+} , a cofactor used by the enzyme. Let V_0 represent the initial velocity of an enzymatic reaction at a given substrate concentration, $[S]$. Below are experimental graphs of

$$V_0 = -K_M \frac{V_0}{[S]} + V_{\max}$$

for five different enzymes and their mutants. Which of the following plots represents the relationship between the wild-type (black) and mutant (red) pancreatic lipase enzyme?

Select ONE.



37. [1.5 pts] Thomas discovered an inhibitor that acts on hexokinase, an enzyme that converts glucose to glucose-6-phosphate. He observes inhibition at low glucose concentrations. The next day, Thomas accidentally dumps his entire container of glucose into his two reaction mixes (enzyme without inhibitor and enzyme with inhibitor), and sees that the rate of the two reactions is the same. What type of inhibitor did Thomas discover? Select ONE.

- a. Noncompetitive Inhibitor
- b. Uncompetitive Inhibitor
- c. Competitive Inhibitor
- d. Suicide Inhibitor
- e. The “inhibitor” is actually the substrate for the enzyme (glucose)

38. [1 pt] Your friend Atharv shows you his latest western blot, shown below, and asks you for help.



Which of the following is the most likely reason for your friend's mishap? Select ONE.

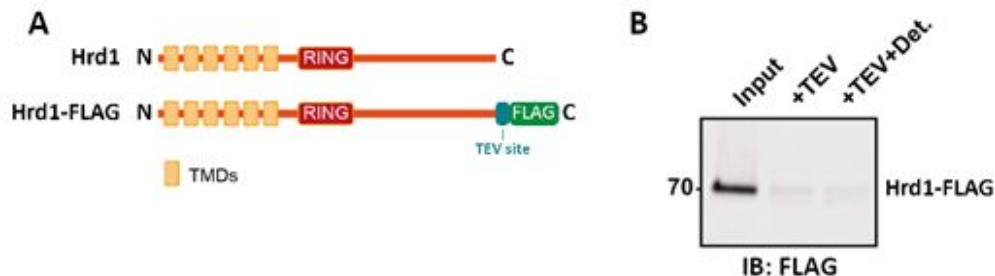
- a. He loaded too much sample in his SDS-PAGE gel
- b. He forgot to load sample into his SDS-PAGE gel
- c. He forgot to add primary antibody
- d. He forgot to add secondary antibody
- e. He forgot to block the membrane with milk

Questions 39-40 are about Hrd1, an ER transmembrane protein.

39. [2 pts] Hrd1 is an ER membrane protein with six transmembrane domains (TMDs) and a RING domain, a family of E3 ubiquitin ligase domains. You want to investigate the RING domain, so you tag Hrd1 with the FLAG epitope on the C-terminus (panel A), isolate microsomes (vesicle-like fragments of ER), and treat them with the following conditions:

- Input: detergent lysis
- +TEV: incubation with TEV protease, a protease that specifically cleaves the TEV protease site, followed by detergent lysis
- +TEV +detergent: incubation with detergent to solubilize microsomes, followed by incubation with TEV protease

Samples from each condition were run on an SDS-PAGE gel and blotted for the FLAG tag, shown in panel B.



Which of the following interpretations is best supported by the data? Select ONE.

- The RING domain of Hrd1 faces the ER lumen
- The RING domain of Hrd1 faces the cytosol
- The RING domain of Hrd1 can face either the ER lumen or the cytosol
- The RING domain is cleaved off of Hrd1 in the mature protein
- Hrd1-FLAG did not express well in yeast so no conclusion can be drawn

40. [1.5 pts] Your friend informs you that Hrd1 is known to be essential for ER-associated protein degradation (ERAD), a process by which misfolded proteins that accumulate during ER stress are exported into the cytosol for degradation by the 26S proteasome. You knock out Hrd1 in yeast. Which of the following predictions about Hrd1 knockout yeast is unreasonable? Select ONE.

- a. Addition of tunicamycin, which induces ER stress, leads to cell death
- b. Misfolded proteins in the ER lumen fail to be exported into the cytosol
- c. Misfolded proteins in the ER lumen fail to be ubiquitinated
- d. ER-stress conditions lead to accumulation of misfolded proteins in the lumen
- e. Hrd1 knockout cells are more sensitive to loss of protein chaperones

41. [1.5 pts] You have discovered a new molecule, Nerd Herd Miracle (NHM), that targets the mitochondria. To determine its function, you purify mitochondria and measure several metrics commonly used to measure mitochondrial function 2 minutes after treatment with NHM.

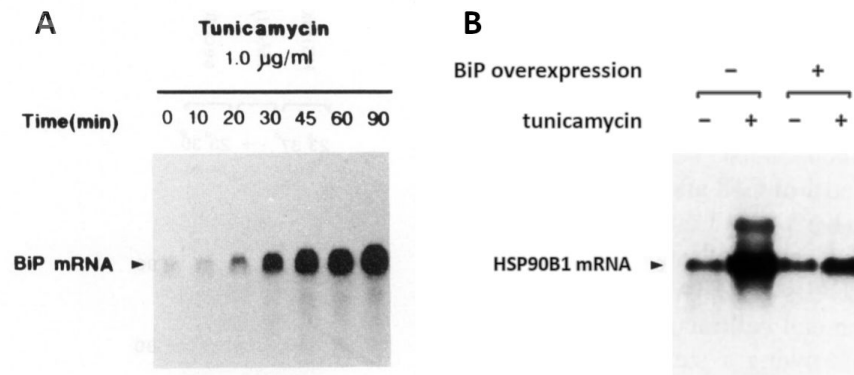
	Experimental	Normal
ATP (μg /mL)	0.2	2.9
NADH (μg /mL)	5.6	2.1
Oxygen consumption (μg /min)	0.01	2.4

Where could glucose metabolism have been disrupted? Select ALL that apply.

- a. Hexokinase is unable to phosphorylate glucose.
- b. Complexes I and II in the ETC are unable to accept electrons.
- c. Pyruvate is unable to enter the mitochondria.
- d. Oxygen is unable to serve as the terminal electron acceptor.
- e. Isocitrate dehydrogenase is unable to convert isocitrate to alpha-ketoglutarate.

Questions 42-43 are about the unfolded protein response.

42. [1.5 pts] The unfolded protein response (UPR) is a cellular program that responds to unfolded protein in the ER. IRE1 senses unfolded proteins in the ER and upregulates expression of various UPR target genes, including ER chaperone protein HSP90B1. BiP is a different ER chaperone protein known to modulate the UPR, but the specific mechanism by which this occurs remains unclear. To study the role of BiP in the UPR, cells were treated with tunicamycin, a drug that induces protein misfolding in the ER, then the levels of BiP mRNA were assessed by northern blot (panel A).



Which of the following conclusions from panel A is most accurate? Select ONE.

- a. Protein misfolding in the ER downregulates transcription of BiP
- b. Protein misfolding in the ER upregulates translation of BiP mRNA
- c. Tunicamycin treatment upregulates BiP mRNA levels
- d. Tunicamycin treatment downregulates BiP protein degradation
- e. BiP upregulates plasma membrane tunicamycin exporters

43. [2 pts] Next, cells overexpressing BiP were treated with tunicamycin, then the levels of HSP90B1 were assessed by northern blot (panel B). Which of the following models is/are consistent with the given data? Select ALL that apply.

- a. IRE1 senses unfolded proteins by directly binding them; BiP binds and sequesters unfolded proteins; accumulation of unfolded proteins beyond BiP binding capacity activates IRE1.
- b. BiP directly binds and inhibits IRE1; unfolded proteins activate IRE1 by preventing the BiP-IRE1 interaction.
- c. BiP is a chaperone for IRE1 folding; the UPR upregulates BiP to enhance IRE1 expression and folding, amplifying the response to ER stress.
- d. BiP is a chaperone for unfolded proteins; the UPR upregulates BiP to bind and clear unfolded proteins from the ER.
- e. BiP is a negative regulator of IRE1; the UPR downregulates BiP to increase IRE1 activation, amplifying the response to ER stress.

44. [1.5 pts] Melody is a researcher from an alien species that specializes in studying human proteins. Unfortunately, she is not very good at her job. After abducting you, Melody agrees to release you on one condition: you must help her identify the human protein whose amino acid sequence is shown below.

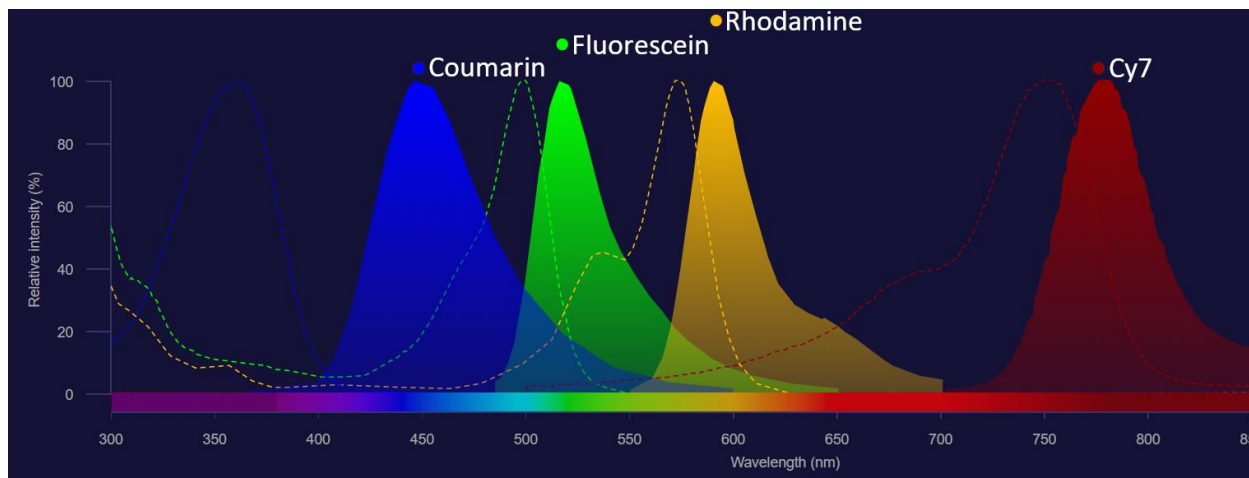
Amino acid sequence, unknown protein

10	20
ALVCMMIALGA	LILMPCLAFWW
30	40
ALAQQSETQRK	RSHTAEQKDIT
50	60
TWGLVATMALI	GAALIGAVLIP

Based on the amino acid sequence, which of the following choices is the most likely cellular location of Melody's protein? Select ONE.

- a. Mitochondrial matrix
- b. Small ribosomal subunit
- c. Plasma membrane
- d. Lysosomal lumen
- e. Chloroplast stroma

45. [1.5 pts] Your friend wants to use fluorescence to determine if proteins A and B form a complex in vitro, so she suggests labeling the two proteins with fluorophores before mixing them. She narrows down potential fluorophores to coumarin, fluorescein, rhodamine, and Cy7, whose excitation and emission spectra are shown below in dashed lines and shaded areas, respectively.



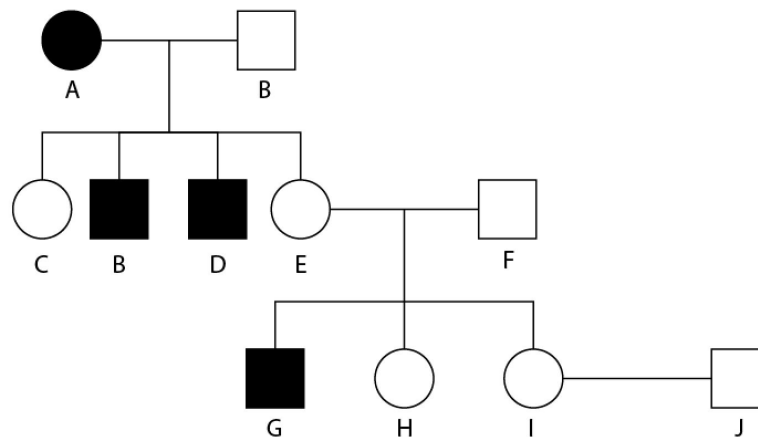
Based on these spectra, which of the following experimental setups would allow your friend to assess whether proteins A and B form a complex? Select ONE.

- a. Label protein A with coumarin, then excite at 350 nm and measure fluorescence at 450 nm.
- b. Label protein A with coumarin and protein B with Cy7, then excite at 350 nm and measure fluorescence at 450 nm.
- c. Label protein A with fluorescein and protein B with rhodamine, then excite at 475 nm and measure fluorescence at 525 nm.
- d. Label protein A with coumarin and protein B with fluorescein, then excite at 350 nm and measure fluorescence at 525 nm.
- e. Label protein A with fluorescein and protein B with Cy7, then excite at 475 nm and measure fluorescence at 775 nm.

Genetics and Evolution

20 questions, 30 points

Questions 46-47 refer to the pedigree below.



46. [1 pt] You are a genetic counselor. The pedigree above traces the inheritance pattern of a rare disease in a family. Individuals F and J come from families with no history of disease. Individuals I and J want to have children, but are asking for your advice. Which of the following statements is/are true? Select ALL that apply.

- a. The pedigree is consistent with an autosomal recessive inheritance pattern.
- b. The pedigree is consistent with an X-linked recessive inheritance pattern.
- c. If individuals A and B had another child, the probability the child would be an affected male is $1/4$.
- d. The probability that individual I is a carrier of the disease is $1/2$.
- e. Without any additional information, the probability that the first child of individuals I and J will be healthy is $5/8$.

47. [1.5 pts] Individuals I and J return several years later, and excitedly inform you that they have had 3 boys and 1 girl, none of whom have had the disease. If they try for a 5th child, what is the probability that the fifth child will have the disease, based on the most probable inheritance pattern? Select ONE.

- a. $1/24$
- b. $1/36$
- c. $3/32$
- d. $1/48$
- e. $5/128$

Questions 48-51 are about a yeast screen for mutants that fail to grow without leucine.

48. [1 pt] Yeast can stably grow as either a haploid or diploid cell. Two haploids can be crossed to obtain a diploid, and one diploid can be sporulated into four haploids, each one a product of meiosis.

Wild-type yeast can grow in the absence of leucine in growth media. You perform a mutagenesis screen and identify a few mutant strains of haploid yeast that cannot grow in media that lacks leucine. You designate these as strains A, B, C, D, E, and F. For simplicity, assume each strain has a single causative mutation that confers the inability to grow in media lacking leucine.

Crossing either strain A or B with haploid wild-type yeast yields diploid yeast that can grow without leucine. However, crossing strain C with haploid wild-type yeast yields diploid yeast that fail to grow without leucine. Which of the following is/are true about the conclusions from this experiment? Select ALL that apply.

- a. Strain A has a recessive mutation in a gene, making it unable to grow in the absence of leucine
- b. Strain A has a dominant mutation in a gene, making it unable to grow in the absence of leucine
- c. Strain C has a recessive mutation in a gene, making it unable to grow in the absence of leucine
- d. Strain C has a dominant mutation in a gene, making it unable to grow in the absence of leucine
- e. Strain C has a codominant mutation in a gene, making it unable to grow in the absence of leucine

49. [1.5 pts] You perform another experiment where you cross haploid strains A and B together to obtain a diploid strain, which you call Z. Interestingly, this new diploid yeast strain can successfully grow in media that lacks leucine. Which of the following statements is/are true about this experiment? Select ALL that apply.

- a. This experiment shows that the mutations causing strains A and B to be unable to grow without leucine are likely located in the same gene
- b. This experiment shows that the mutations causing strains A and B to be unable to grow without leucine are likely located in different genes
- c. Sporulating strain Z into 4 haploids will result in all 4 daughter haploid yeast being unable to grow on media lacking leucine
- d. Sporulating strain Z into 4 haploids will result in all 4 daughter haploid yeast being able to grow on media lacking leucine
- e. Based on these findings so far, crossing strain A and C to form a diploid would also produce a strain that successfully grows in media lacking leucine.

50. [1 pt] To follow up on these experiments, you cross each of strains D, E, and F with a haploid wild-type strain, and find that each resultant diploid is able to grow in leucine-free media. You then perform pairwise crosses of each of the strains A, B, C, D, E, F with each other and see which resultant diploids can grow in leucine-free media. Your results are summarized in the table below. Here, + indicates growth on leucine-free media, while – indicates the inability to grow on leucine-free media.

	Strain A	Strain B	Strain C	Strain D	Strain E	Strain F
Strain A	N/A	+	-	+	-	+
Strain B	+	N/A	-	-	+	+
Strain C	-	-	N/A	-	-	-
Strain D	+	-	-	N/A	+	+
Strain E	-	+	-	+	N/A	+
Strain F	+	+	-	+	+	N/A

What is the minimum number of genes in which these 6 mutations occur? Select ONE.

- a. 1
- b. 2
- c. 3
- d. 4
- e. 6

51. [2 pts] You next want to study the genetic relation between strains A and F. To do so, you cross haploid strain A with haploid strain F to obtain diploid strain X. You then grow diploid strain X and sporulate 100 different cells from this strain to form 4 haploid daughter cells through meiosis. Interestingly, 48 times when you do this, all 4 of the cells cannot grow without leucine, but 52 times, 2 of the 4 haploid cells can grow without leucine, while the other two cannot grow without leucine. Which of the following statements represent(s) likely conclusions from this experiment? Select ALL that apply.

- a. Strains A and F contain mutations in the same gene
- b. Strains A and F likely contain mutations in different genes on different chromosomes.
- c. Strains A and F likely contain mutations in different genes on the same chromosome.
- d. The chromosomal distance between the two genes in which the two mutations occur is approximately 4 centimorgans.
- e. The chromosomal distance between the two genes in which the two mutations occur is approximately 24 centimorgans.

52. [1.5 pts] In a typical eukaryotic cell, the mitochondrial DNA (mtDNA) is shorter and less complex than the nuclear DNA (nDNA). Which of the following is/are true? Select ALL that apply.

- a. Migration of mtDNA to the nucleus is largely responsible for the significantly decreased length of mtDNA compared to the DNA of the prokaryotic ancestor of the mitochondria.
- b. The prokaryotic ancestor of the mitochondria involved in endosymbiosis contained very little DNA compared to the DNA of the eukaryotic ancestor, thus contributing to the disparity between mtDNA and nDNA in modern eukaryotes.
- c. A mitochondrial genome that causes rapid, unregulated mitochondrial replication is positively selected for by the mitochondria, but negatively selected for by the cell as a whole.
- d. A vanishingly small mitochondrial genome is positively selected for by both the mitochondria and the cell as a whole.
- e. Eukaryotic cells that lack mtDNA would necessarily have higher fitness than eukaryotic cells with a standard amount of mtDNA.

53. [1.5 pts] You are a geneticist studying *Giraffa camelopardalis*. You discover that, apart from the wildtype yellow phenotype, there exist white and orange phenotypes. After much patience, you successfully produce a true-breeding yellow population and a true-breeding white population. When you cross these two strains, you get only yellow offspring. When you cross the resulting yellow individuals amongst themselves, you get 130 offspring, with 73 yellow, 24 orange, and 33 white. Based on this information, which of the following is most likely to be true? Select ONE.

- a. Breeding the resultant orange offspring with the yellow offspring will result in only white offspring being produced.
- b. The enzyme directly responsible for producing yellow pigment is mutated in all the white offspring.
- c. The enzyme directly responsible for producing orange pigment is mutated in all the white offspring.
- d. Breeding the white offspring with themselves will result in some orange offspring.
- e. The enzyme directly responsible for producing white pigment is mutated in all the yellow offspring.

54. [1.5 pts] After suffering severe memory loss following the birth of her child, a mother is confronted with a surprising dilemma when three different men, Individual 1, Individual 2, and Individual 3, all claim to be the father. Unable to handle the drama, the mother orders several genetic screenings to determine her child's true paternity, the results of which are shown below.

Individual	Blood Type	CDA414
Individual 1	A ⁺	23/25
Individual 2	B ⁻	17/23
Individual 3	AB ⁺	17/25
Mother	O ⁻	15/17
Child	B ⁺	17/25

The genetic screens were blood type and STR analysis for CDA414, an STR located on chromosome 14.

Assuming that one of the three individuals is the father, which of the following statements is true? Select ALL that apply.

- a. After ruling out Individuals 2 and 3, Individual 1 is the father.
 - b. After ruling out Individuals 1 and 2, Individual 3 is the father.
 - c. Since there are three individuals claiming paternity, an additional genetic screen must be used to conclusively identify the father.
 - d. Given the ABO and CDA414 screens, screening for Rh factor is not necessary to identify the father from the three individuals.
 - e. If the mother has another Rh⁺ pregnancy, the mother risks eliciting a potentially destructive, hemolytic immune response against the fetus.
55. [1.5 pts] You are studying a population of pufferfish at Hardy-Weinberg equilibrium. In these pufferfish, the recessive mutation *explody* weakens outer connective tissues up until sexual maturity is reached, causing many immature pufferfish to fatally rupture upon inflating. In fact, 50% of homozygous *explody* individuals die before reaching sexual maturity. If the population's allele frequency of *explody* at the end of Generation 0 is 0.2, what percentage of Generation 2's pufferfish will fatally rupture due to *explody*? Select ONE (the closest answer choice).
- a. 1.69%
 - b. 2.88%
 - c. 3.38%
 - d. 6.01%
 - e. 12.02%

56. [2 pts] Under the neutral theory of molecular evolution, genetic drift rather than natural selection drives evolution of species. The McDonald-Kreitman (MK) test estimates the role of natural selection in evolution by comparing mutations within a species and between species. Consider two species, *Drosophila simulans* and *D. yakuba*, which diverged 6 million years ago. Mutations within a species are polymorphisms (P) while mutations between species are substitutions (D). Mutations can be synonymous (P_s and D_s), coding for the same amino acid, or non-synonymous (P_n and D_n), coding for a different amino acid. The MK test produces a statistic

$$\alpha = 1 - \frac{D_s P_n}{D_n P_s} = \frac{a}{D_n}$$

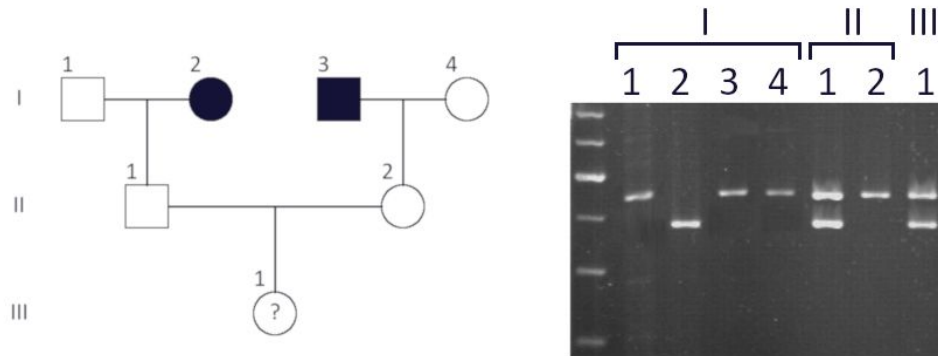
where a is the number of substitutions fixed due to adaptive evolution. For *D. simulans* compared to *D. yakuba*, the mutation counts are:

	Synonymous	Non-synonymous
Polymorphism	$P_s = 759$	$P_n = 162$
Substitution	$D_s = 565$	$D_n = 273$

Which of the following is/are true about the MK test and the evolution of the two *Drosophila* species? Select ALL that apply.

- In the null hypothesis where evolution is driven entirely by genetic drift of neutral mutations, α is equal to 1.
- A higher value of α suggests a larger role of natural selection in driving evolution.
- Since the divergence of the two *Drosophila* species, approximately 56% of non-synonymous substitutions became fixed due to natural selection.
- Since the divergence of the two *Drosophila* species, approximately 56% of synonymous substitutions became fixed due to natural selection.
- If the two *Drosophila* species differ by 593,776 non-synonymous substitutions, then on average, an adaptive substitution occurs in the *D. simulans* lineage once every 18 years.

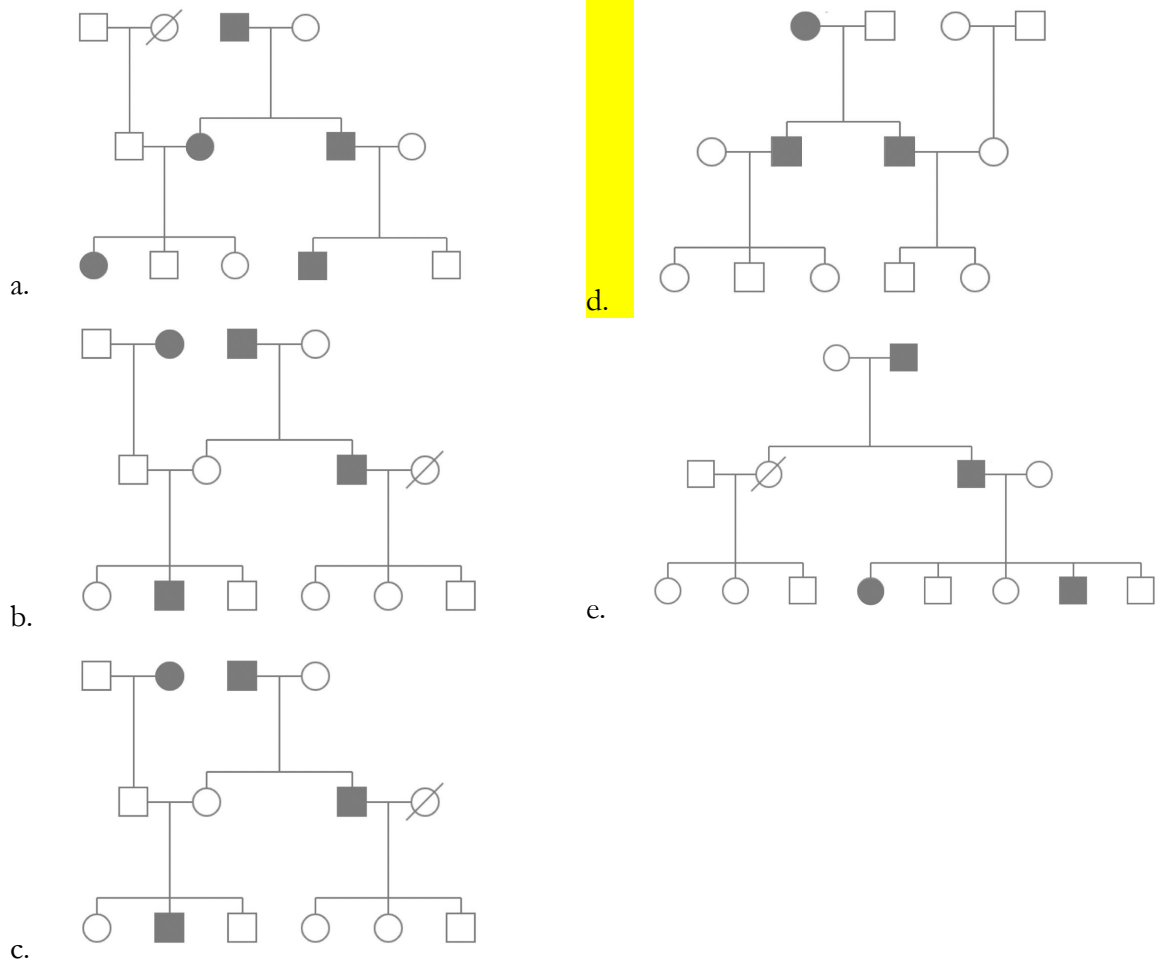
57. [1.5 pts] Oak syndrome, an autosomal recessive disease which manifests at around age 10, is linked to a short tandem repeat locus with an observed recombination frequency of 8%. Two individuals (II-1 and II-2), who each had a parent with Oak syndrome, have a newborn daughter (III-1) and are worried about her getting Oak syndrome. A quick genetic test consisting of PCR amplification of the linked short tandem repeat locus yielded the following results:



Based on this information, what is the probability that the newborn daughter (III-1) will develop Oak syndrome later in life? Select ONE.

- a. 4%
- b. 23%
- c. 25%
- d. 46%
- e. 100%

58. [1 pt] Which of the following pedigrees is most likely showing a rare disease with a sex-linked recessive inheritance pattern? Select ONE.



59. [1 pt] Which of the following is an example of sympatric speciation? Select ONE.

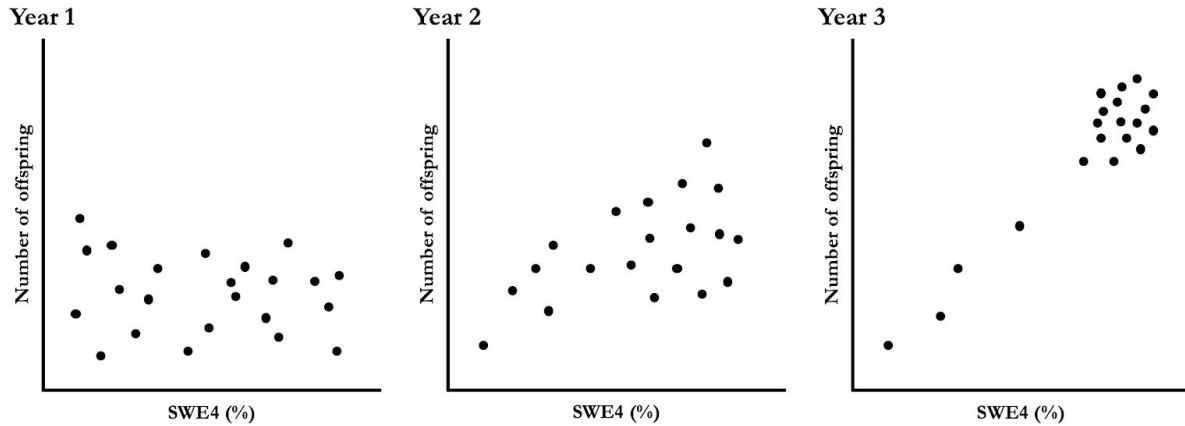
- a. The formation of a new mountain range splits a population of goats into two, and the populations become two separate species over time.
- b. Errors in meiosis result in the formation of a grass with four sets of chromosomes instead of two; this tetraploid grass is unable to produce viable offspring.
- c. A natural disaster decimates a population of shrews and results in the fixation of deleterious alleles.
- d. A population of orca splits into two species due to sexual selection and development of different environmental niches within their northeast Pacific Ocean habitat.**
- e. A population of horses and a population of donkeys inhabit the same field, leading to the production of hybrids (mules and hinnies) that are largely infertile.

60. [2 pts] You are studying League of Legends ability in moths, which you know is controlled by a single sex-linked gene called *League*. Victorious moths (V) have a more than a 50% win rate in League of Legends, while losing moths (L) have a less than a 50% win rate. Crosses were made between different V and L moths, shown in the table below. Which of the following statements is accurate? Note that ♀ indicates the female population and ♂ indicates the male population. Select ALL that apply.

Cross	P	F1	F2
1	♀: L ♂: V	♀: V ♂: V	♀: ½ L, ½ V ♂: V
2	♀: V ♂: L	♀: L ♂: V	♀: ½ L, ½ V ♂: ½ L, ½ V

- The P generation females from Cross 1 are homozygous for the recessive allele of the League gene
- Male moths are hemizygous for the League gene
- If the F1 generation females from Cross 1 were mated with the F1 generation males from Cross 2, all of the male offspring would have the victorious (V) phenotype
- The F2 generation males from Cross 1 do not all have the same genotype
- The F1 generation males from Cross 2 are heterozygous for the League gene

61. [1.5 pts] There is a species of nontoxic frogs that express a vibrant, orange skin pigment known as SWE4. Frogs in a specific population of this species can have varying amounts of SWE4 when measured as a percentage of total skin pigment. Your sharp biological skills hint to you that SWE4 may play a selective role, so you measure the number of offspring produced by frogs with varying levels of SWE4 over several years. Your results are shown in the figures below.



Each dot represents 5 frog individuals.

Which of the following types of selection is SWE4 subject to in your frog population?
Select ONE.

- a. Stabilizing
- b. Diversifying
- c. Disruptive
- d. Negative frequency-dependent
- e. Positive frequency-dependent

62. [1.5 pts] Mregor Gendel believes that the color of the pea plants is controlled by a single autosomal gene, with the dominant allele resulting in rainbow-colored plants and the recessive allele resulting in transparent plants. He crosses a true-breeding group of rainbow plants with a true-breeding group of transparent plants, then performs crosses the F1 generation with each other. The results of the F2 generation are displayed below. Mregor Gendel uses a chi-square goodness of fit test to determine if his prediction of an autosomal dominant inheritance pattern for pea plant color is correct. What can he conclude? Assume that $p < 0.05$ indicates a statistically significant difference. The equation for the chi-square goodness of fit test is provided below as well as a table showing chi-square critical values. Select ONE.

Pea Plant Color	Number
Rainbow	341
Transparent	23

Critical values for χ^2 test				
p-val DF	0.1	0.05	0.01	0.005
1	2.706	3.84	6.64	7.88
2	4.605	5.99	9.21	10.60
3	6.251	7.82	11.35	12.94
4	7.779	9.49	13.28	14.86

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

O = the frequencies observed

E = the frequencies expected

\sum = the 'sum of'

- Since the chi-square value is 214.6, which corresponds to $p > 0.05$, Mregor can conclude that pea plant color is due to autosomal dominant inheritance.
- Since the chi-square value is 214.6, which corresponds to $p < 0.05$, Mregor can conclude that pea plant color is not due to autosomal dominant inheritance.
- Since the chi-square value is 93.2, which corresponds to $p < 0.05$, Mregor can conclude that pea plant color is not due to autosomal dominant inheritance.
- Since the chi-square value is 67.8, which corresponds to $p > 0.05$, Mregor can conclude that pea plant color is due to autosomal dominant inheritance.
- Since the chi-square value is 67.8, which corresponds to $p < 0.05$, Mregor can conclude that pea plant color is not due to autosomal dominant inheritance.

Questions 63-64 are about three linked genes.

63. [1.5 pts] You want to study the relationship between three genes (a, b, and c) in *Rosophilo*, which you know are on the same chromosome. You cross a true-breeding wild type (+ + +) *Rosophilo* with a triply-recessive (a b c) *Rosophilo*. The resulting F1 *Rosophilo* are then testcrossed to another triply-recessive individual, giving you the following result below. What is the order of the three genes and the distance between them? Select ONE.

Genotype	Observed # of F2
abc	1552
+++	1531
+bc	2
a++	1
+b+	110
a+c	101
ab+	27
++c	25
Total	3349

- a. c----1.64 cM----a----6.39 cM----b
- b. a----6.39 cM----b----1.64 cM----c
- c. b----8.02 cM----a----1.10 cM----c
- d. b----6.33 cM----a----1.51 cM----c
- e. c----4.12 cM----a----3.81 cM----b

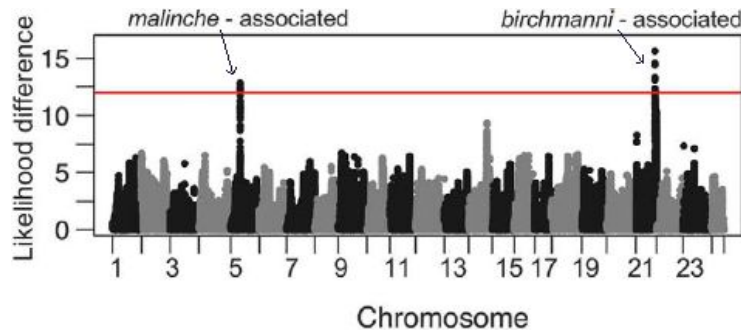
64. [2 pts] Interference occurs when crossing over in one part of a chromosome influences crossing over in other regions of the same chromosome. Interference (I) can be calculated from the coefficient of coincidence (C) by the following equations. Note: DCO = number of double crossovers. Using the data from your previous crosses with the a, b and c genes in *Rosophilo*, what is the interference from this cross? Use the rounded values from the previous question in your calculations. Select ONE.

$$I = 1 - C$$

$$C = \frac{\text{observedDCO}}{\text{expectedDCO}}$$

- a. -0.230
- b. 0.217
- c. -0.143
- d. 0.145
- e. 0.434

65. [2 pts] You discover a population of swordtail fish (genus *Xiphophorus*) which resulted from interbreeding between two distinct but closely related species, *X. birchmanni* and *X. malinche*; you notice that in this hybrid population, many fish have melanomas. You perform admixture mapping, in which hybrid individuals are sequenced, and at each locus the ancestry, *birchmanni* or *malinche*, is inferred using genetic markers; the ancestry at each locus is then correlated with the phenotype, in this case melanoma. The results are shown below, with the ancestry association labeled at statistically significantly correlated loci.



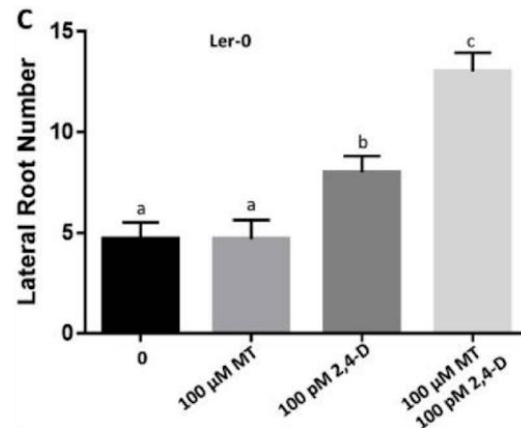
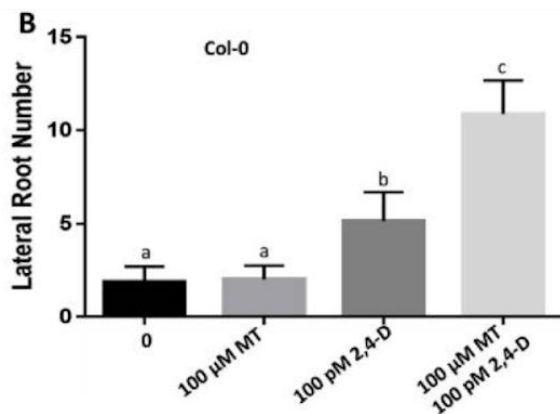
Which of the following claims is/are supported by the data? Select ALL that apply.

- Melanoma occurrence is a selective disadvantage for both *X. malinche* and *X. birchmanni* compared to other *Xiphophorus* species.
- Incompatibility between a *X. malinche* allele on chromosome 5 and a *X. birchmanni* allele on chromosome 21 likely underlies melanoma in this population
- These results map the genetic basis for a hybrid incompatibility in *X. birchmanni*–*X. malinche* hybrids.
- These results map the distinct genetic bases for melanoma occurrence in both *X. birchmanni* and *X. malinche* species.
- An individual with heterozygous ancestry for both loci on chromosomes 5 and 21 is more likely to develop melanoma than an individual with homozygous ancestry at either locus.

Plant Anatomy and Physiology

15 questions, 22.5 points

66. [1.5 pts] To investigate the role of melatonin and auxin on lateral root development, you take seedlings from two different *Arabidopsis* ecotypes (Col-0 and Ler-0) and treat them with 100 μ M melatonin (MT), 100 pM 2,4-D (a synthetic auxin), a combination of both, or no treatment (0). After 9 days, you count the number of lateral roots on each seedling, and the data is displayed below. What conclusion can you make from this experiment? Select ONE.



- a. Melatonin and auxin treatment resulted in more lateral root formation in the Col-0 ecotype when compared to the Ler-0 ecotype
- b. Melatonin and auxin had a synergistic effect on lateral root number in the Col-0 ecotype, but not the Ler-0 ecotype
- c. Melatonin and auxin treatment both increase the lateral root number in Col-0 and Ler-0, and seem to have additive effect on lateral root number when combined
- d. Melatonin treatment alone did not affect lateral root number in Col-0 and Ler-0, but seems to have a synergistic effect on lateral root number when combined with auxin treatment
- e. Melatonin does not have a role in lateral root development in Col-0 and Ler-0; auxin alone is responsible for increases in lateral root number

67. [1.5 pts] After Melody carefully removes a cross-section from a mystery plant, she views her freshly cut section under a light microscope (pictured below).

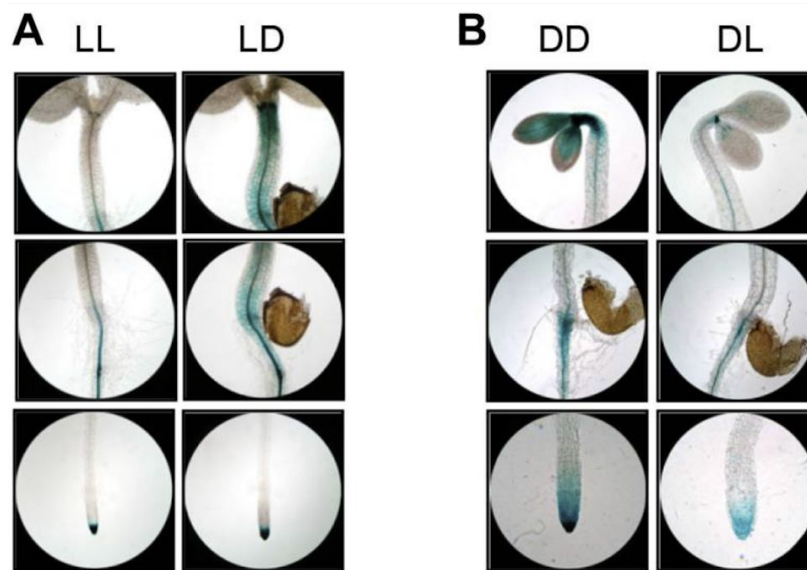


Which of the following statements is/are true? Select ALL that apply.

- a. Melody's cross-section comes from a leaf.
- b. The structure circled in red is a sclerenchyma cell but not a sclereid.
- c. The large, intracellular spaces shown in Melody's cross-section efficiently store water for periods of drought or low rainfall.
- d. Melody's plant is highly adapted to survive in an aquatic environment.
- e. Plants adapted to the same environment that Melody's plant species lives in are characterized by thick, waxy cuticles.

Questions 68-70 are about ethylene in seedlings.

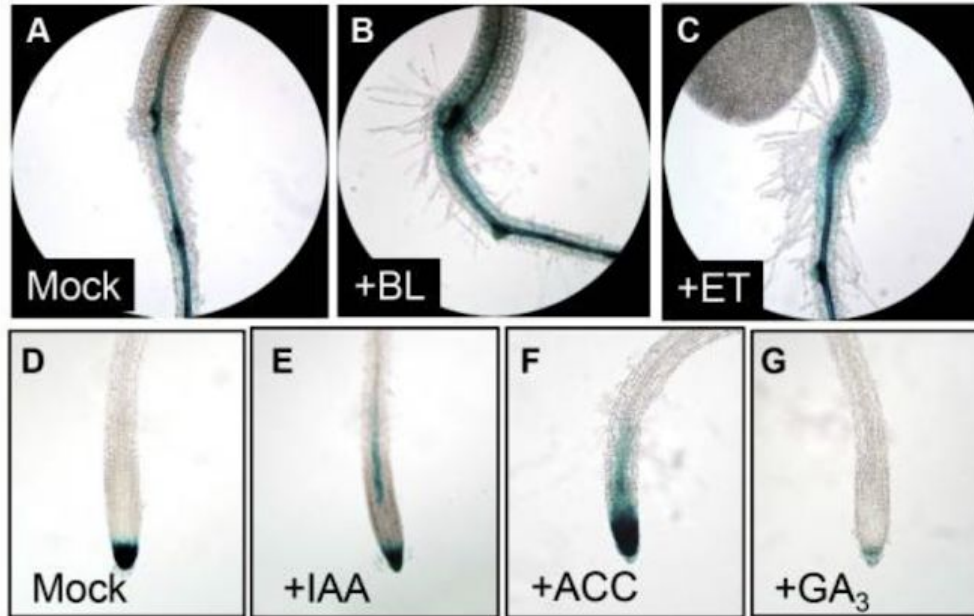
68. [2 pts] You wish to study the expression of a certain gene involved in the synthesis of ethylene, which you name CEE. You fuse a bacterial β -glucuronidase reporter gene with the promoter of CEE to form CEE-GUS plants. Upon addition of a substrate that becomes blue after catalysis by β -glucuronidase, you are able to study the expression of CEE within the plant. Using this system, you study CEE-GUS seedlings grown in light before (LL) and after (LD) transitioning the seedlings to a dark environment. In addition, you also study the GUS expression of CEE-GUS seedlings grown in dark before (DD) and after (DL) transitioning the seedlings to a lit environment. The results are displayed below.



What do you learn about CEE from these results? Select ALL that apply.

- a. The light-to-dark transition increased CEE expression in the cotyledon, hypocotyl-root junction, and the roots
- b. The dark-to-light transition reduced CEE expression in the cotyledon, hypocotyl-root junction, and the roots
- c. The light-to-dark transition increased CEE expression in the hypocotyl and in the hypocotyl-root junction, but not the cotyledons
- d. CEE expression is more dependent on the light-to-dark transition than the dark-to-light transition
- e. Light-grown and dark-grown CEE-GUS seedlings had similar levels of CEE expression at the hypocotyl-root junction

69. [2 pts] Continuing your investigation of the regulation of ethylene biosynthesis, you treat your CEE-GUS plants with BL (a brassinosteroid), ET (ethylene), IAA (auxin), ACC (1-aminocyclopropane-1-carboxylic acid, an intermediate in ethylene biosynthesis), and GA3 (a gibberellin). You observe the GUS expression in your CEE-GUS plants after the different treatments, as compared to the control (mock, no treatment). Your results are shown below. What can you conclude from these results? Select ALL that apply.



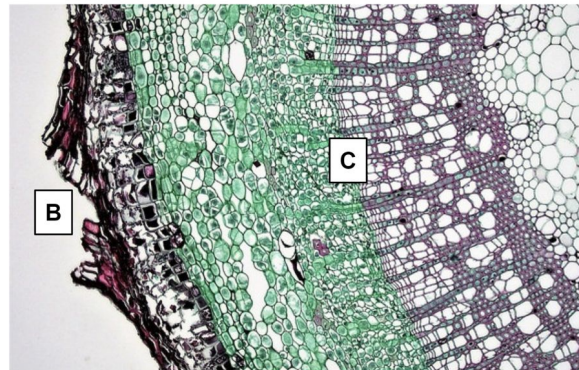
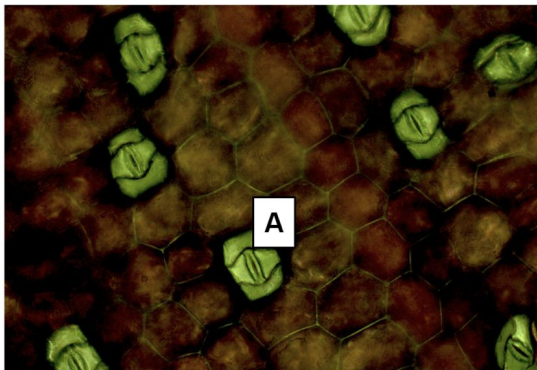
- a. Auxin and ACC treatment both increased CEE expression in the root elongation zone
- b. Gibberellins primarily decreased CEE expression in the root maturation zone
- c. Auxin and ACC treatment both increased CEE expression from the root tip to the root elongation zone
- d. CEE is basally expressed in the root tip and root elongation zones, but not the root maturation zone
- e. Brassinosteroid and ethylene treatment enhanced CEE expression in both the root maturation zone and hypocotyl, as compared to controls

70. [1.5 pts] In one of your treatments, you observed a noticeable difference between treated (right) and untreated (left) plants. Which treatment was this? Select ONE.



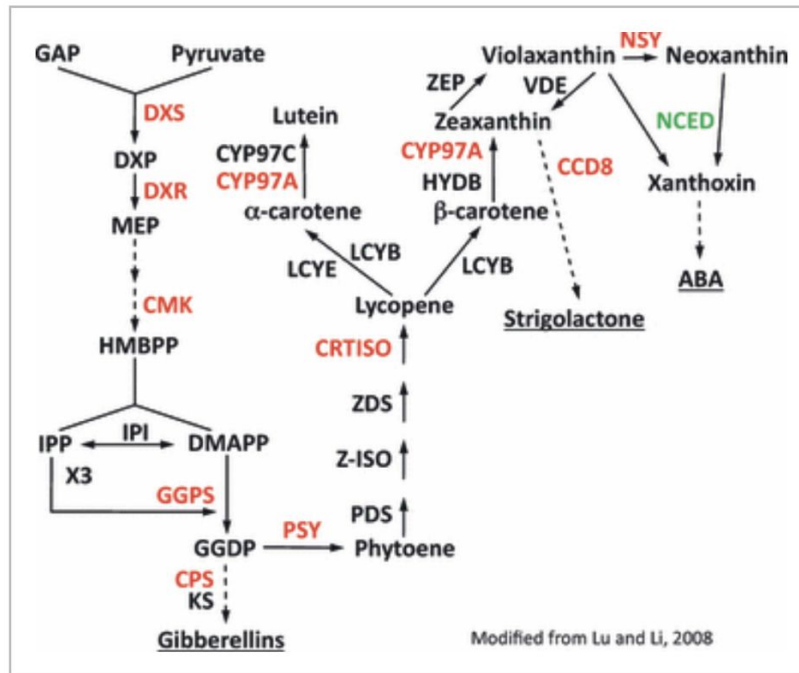
- a. BL
- b. ET
- c. IAA
- d. ACC
- e. GA3

71. [1 pt] Which of the following is/are true about the images below? Select ALL that apply.



- a. Both the left and right images come from eudicots
- b. Both images contain structures that facilitate gas exchange
- c. The structure labeled "A" is responsible for evapotranspiration
- d. The boundary region labeled "B" is active in herbaceous stems
- e. The activity of the structure labeled "C" is regulated by abscisic acid

72. [2 pts] Shown below are the biosynthetic pathways of various plant hormones. Enzymes shown in red are known to be downregulated in response to environmental phosphate, while enzymes shown in green are upregulated.



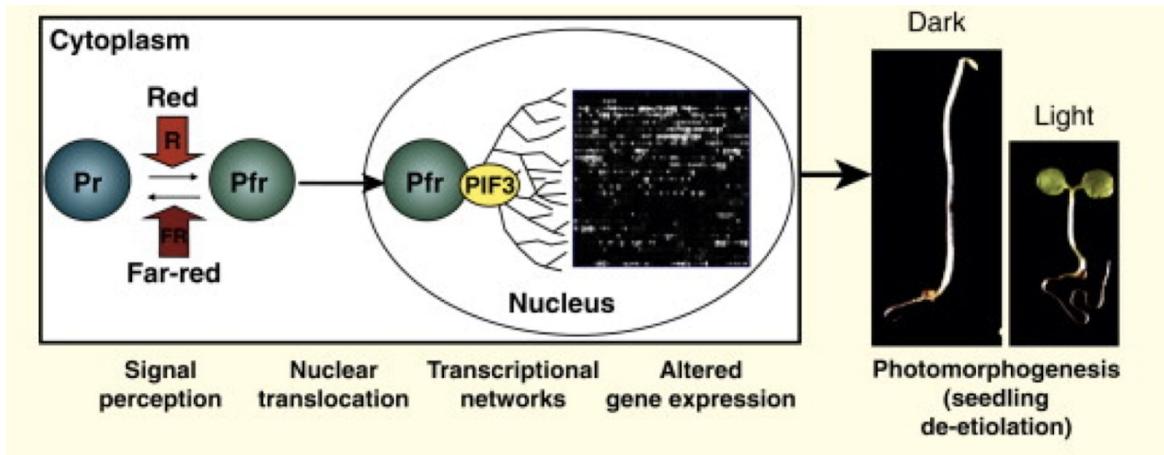
Which of the following statements are true? Select ALL that apply.

- Increased phosphate levels must lead to an increase in ABA synthesis
- An NCED knockout mutant would likely be more sensitive to drought conditions compared to wildtype
- An increase in environmental phosphate likely decreases mycorrhizae recruitment
- Given that the condensation of GAP and pyruvate leads to the formation of DXP and one molecule of CO₂, DXP must be a pentose
- Overactivity of CPS will lead to impaired apical dominance and increased internodal elongation

73. [1 pt] Which of the following could you expect to find in a eudicot plant stem undergoing secondary growth but not in a eudicot plant stem undergoing only primary growth? Select ONE.

- Pith
- Primary phloem
- Primary xylem
- Phelloderm
- Epidermis

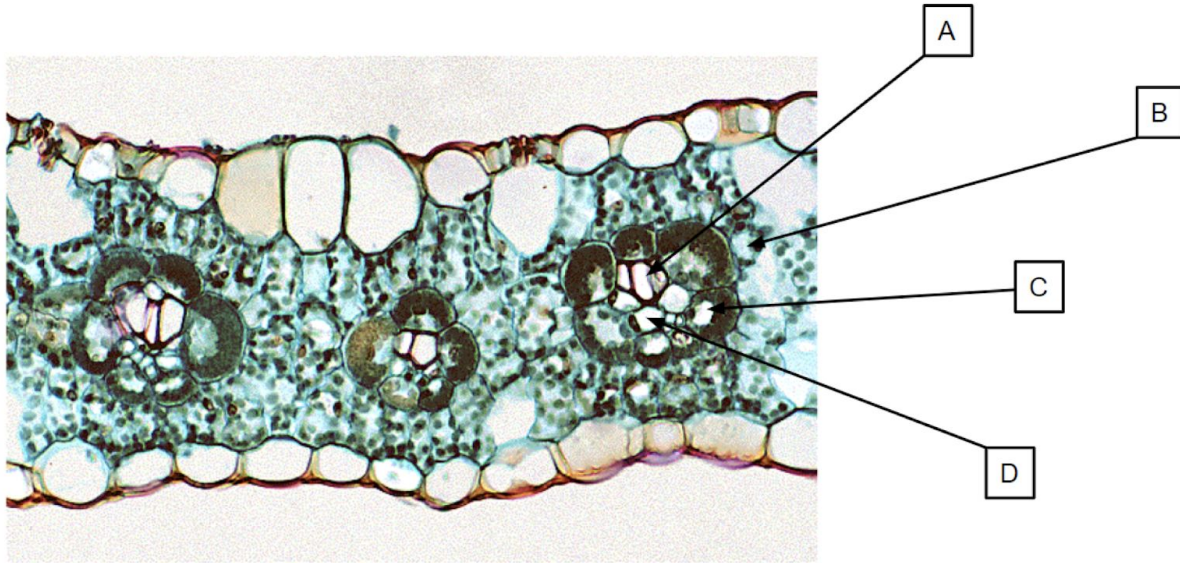
74. [2 pts] Plant seedlings germinate at appropriate times in the year due to photosensing by phytochromes. As shown in the figure below, phytochromes are photoconvertible proteins that regulate gene expression upon translocating to the nucleus. It has been shown that nuclear localization of Pfr leads to the rapid phosphorylation and ubiquitination of PIF3, a growth-promoting transcription factor.



Which of the following is/are true? Select ALL that apply.

- a. The light-sensitive portion of the phytochrome protein requires a cofactor
- b. Knocking out PIF3 would cause dark-grown seedlings to copy the development of light-grown wildtype seedlings
- c. Phytochrome is synthesized in its Pfr form and degraded in its Pr form
- d. Based on its activity, Pfr can be considered a protein phosphatase
- e. DNA-sequencing of light-treated seedlings is an appropriate method to study light-induced changes in gene expression

Questions 75-78 refer to the plant section below. Note that the top of the plant section (near “A”) is the adaxial surface and the bottom of the section (near “D”) is the abaxial surface. Not all answer choices will be used.



75. [1.5 pts] Which is true about A? Select ONE.

- a. This cell is dead at maturity
- b. This cell fixes CO₂ to form glyceraldehyde 3-phosphate
- c. This cell produces and secretes suberin
- d. This cell can be described as collenchyma
- e. This cell fixes CO₂ to form oxaloacetate

76. [1.5 pts] Which is true about B? Select ONE.

- a. This cell is dead at maturity
- b. This cell fixes CO₂ to form glyceraldehyde 3-phosphate
- c. This cell produces and secretes suberin
- d. This cell can be described as collenchyma
- e. This cell fixes CO₂ to form oxaloacetate

77. [1.5 pts] Which is true about C? Select ONE.

- a. This cell is dead at maturity
- b. This cell fixes CO₂ to form glyceraldehyde 3-phosphate
- c. This cell produces and secretes suberin
- d. This cell can be described as collenchyma
- e. This cell fixes CO₂ to form oxaloacetate

78. [1 pt] What is true about this plant? Select ONE.

- a. The plant that this specimen came from is well-adapted for increasing global temperatures
- b. This plant produces more 2-phosphoglycolate as a byproduct of its metabolism than most plants
- c. This plant exclusively fixes carbon dioxide at night to reduce water loss
- d. Most of the stomata on this plant are located on the upper face of the leaf
- e. In this plant, sugars are produced in the mesophyll

79. [1 pt] During an intense exam, you are asked to determine the biological importance of root caps, a type of specialized tissue at the tip of plant roots. To do so, you recall a scenario from class in which a flowering plant has its root cap delicately removed. Which of the following is likely to occur in this scenario? Select ALL that apply.

- a. The root is equally likely to grow upwards or downwards relative to gravity.
- b. The root will face less resistance when penetrating soil during growth.
- c. The plant will have a reduced ability to interact with beneficial soil bacteria and will be more susceptible to predators.
- d. Since auxin is primarily transported from the base to the tip of the root, removing the root cap will cause auxin to leak into the root's surroundings at nearly the same rate it is produced.
- e. Removal of the root cap will leave the root's apical meristem exposed to the surrounding environment.

80. [1.5 pts] You are interested in the mechanisms that your two favorite plants utilize to prevent self-fertilization. Plant A utilizes gametophytic self-incompatibility, whereas Plant B utilizes sporophytic self-incompatibility. These plants are able to pollinate each other, so they are perfect for study! Previous research demonstrates that incompatibility is controlled by the *S* locus. Based on genome sequencing, you know that Plant A's genotype at this locus is S_1S_2 , and Plant B's genotype at this locus is S_2S_3 . Which of the following is/are true? Select ALL that apply.

- a. Pollen from Plant A will fail to fertilize eggs from Plant A 50% of the time.
- b. Pollen from Plant A will fail to fertilize eggs from Plant B 50% of the time.
- c. Pollen from Plant B will fail to fertilize eggs from Plant A 50% of the time.
- d. If pollen from Plant B fails to fertilize eggs from Plant A, it is because of a signal transduction pathway in the epidermal cells of the stigma that prevents germination of the pollen grain.
- e. If pollen from Plant A fails to fertilize eggs from Plant B, it is because the egg detects the pollen as "self," and the pollen releases enzymes that destroy its RNA.

Ecology

10 questions, 15 points

Questions 81-82 refer to the following life table of a mystery mammal species. Values A-M are missing from the life table.

Age class	Number alive	Number dying	Proportion surviving	Mortality rate	Fecundity
0	A	982	1.000	0.818	0.0
1	218	73	0.182	J	0.5
2	B	D	0.121	0.042	1.0
3	95	37	F	0.031	5.0
4	58	E	G	K	1.0
5	17	9	0.014	L	0.0
6	C	8	H	M	0.0

81. [1.5 pts] Which of the following statements is true? Select ALL that apply.

- a. This species is most likely r -selected.
- b. The initial population size was 1200 individuals.
- c. Values B and D are equal to 145 and 50, respectively.
- d. Values G and J are equal to 0.048 and 0.061, respectively.
- e. Values H and M are equivalent.

82. [2 pts] Assuming that 50% of the species population is female, which of the following values is the closest approximation of lifetime offspring produced for an individual in age class 1? Select ONE.

- a. 3.60
- b. 3.97
- c. 5.16
- d. 6.88
- e. 9.32

83. [2 pts] While studying meese, you find that the number of meese in two adjacent populations can be modeled using the following equations. Note that $a(x)$ is the population of population A at x years and $b(x)$ is the population of population B at x years.

$$a(t + 1) = 0.7a(t) + 0.3b(t)$$

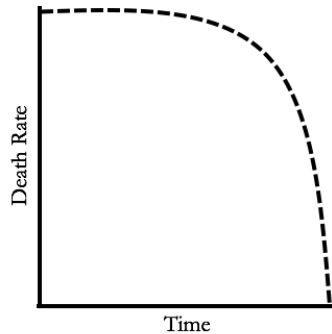
$$b(t + 1) = 0.3a(t) + 0.7b(t)$$

Currently, population A has 500 meeses, while population B has 5000 meeses. Which of the following is true? Select ONE.

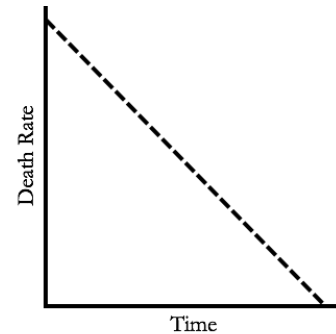
- a. The two populations will coexist with a higher population A
- b. The two populations will coexist with a higher population B
- c. The two populations will coexist with equal populations
- d. Population A will disappear, leaving only population B
- e. Population B will disappear, leaving only population A

84. [1.5 pts] *Avadis kedavrum* is a recently discovered species endemic to Grainge Island.

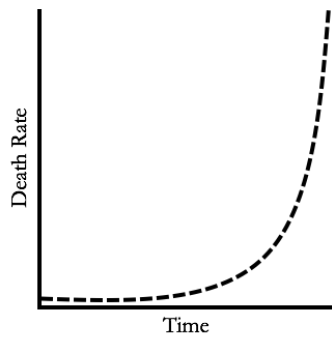
The life cycle of *A. kedavrum* is as follows: individuals are born in cohorts of 2-3 siblings, metamorphose into their adult form after 7 years of full-time care by both parents, and undergo 1-2 reproductive events before dying en masse at an age of 10 years. Populations of this species are also unique in that they exhibit completely random mating with no actively sexual selection. Which of the following is the most accurate mortality curve for a generation of *A. kedavrum* individuals? Select ONE.



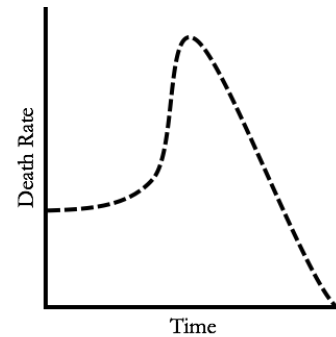
a.



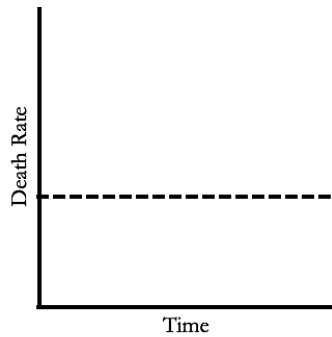
d.



b.

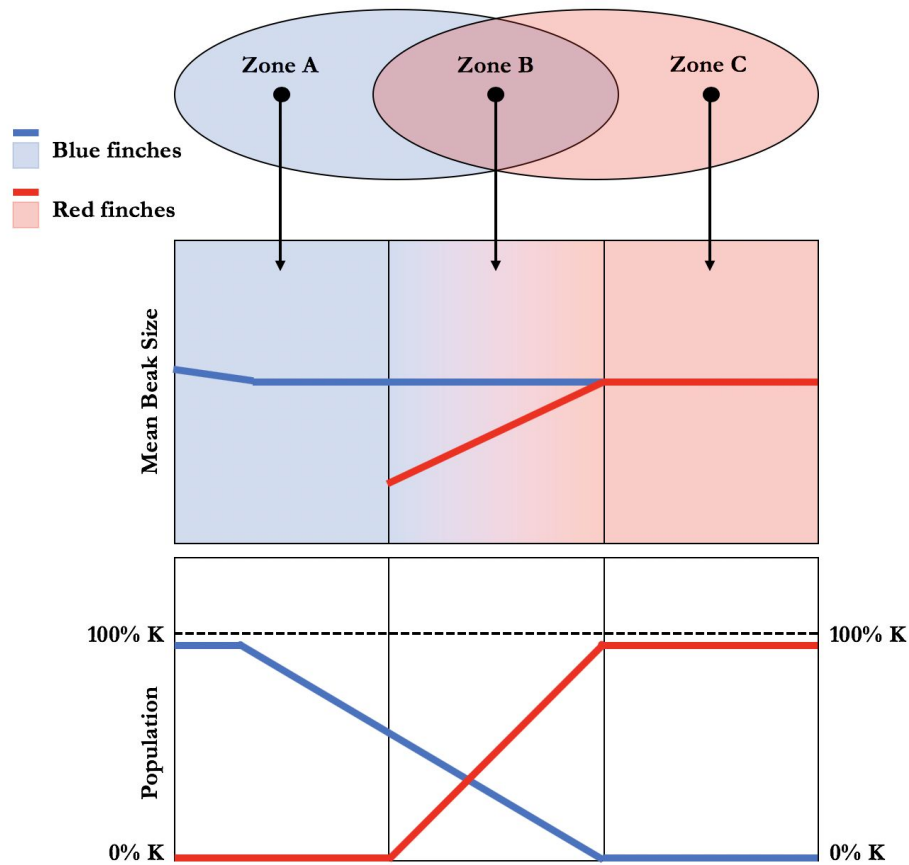


e.



c.

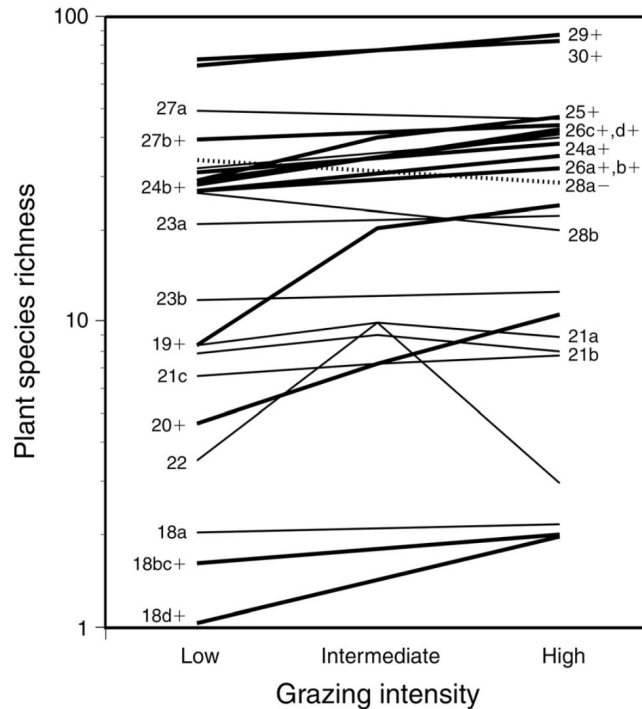
85. [1.5 pts] Blue finches and red finches are two avian species endemic to the Color Mountains. Zones A-C show the spatial distribution of blue finches and red finches, and each graph below corresponds to one zone.



Which of the following statements are true? Select **ALL** that apply.

- a. Blue finches are weakly directionally selected as their population nears carrying capacity.
- b. Red finches likely have the same fundamental and realized niche in Zone B.
- c. At some point in the past, blue finches outcompeted red finches in Zone B.
- d. Red finches will eventually go extinct in Zone B.
- e. Based on mean beak size staying constant throughout, red finches are not directionally selected in Zone C.

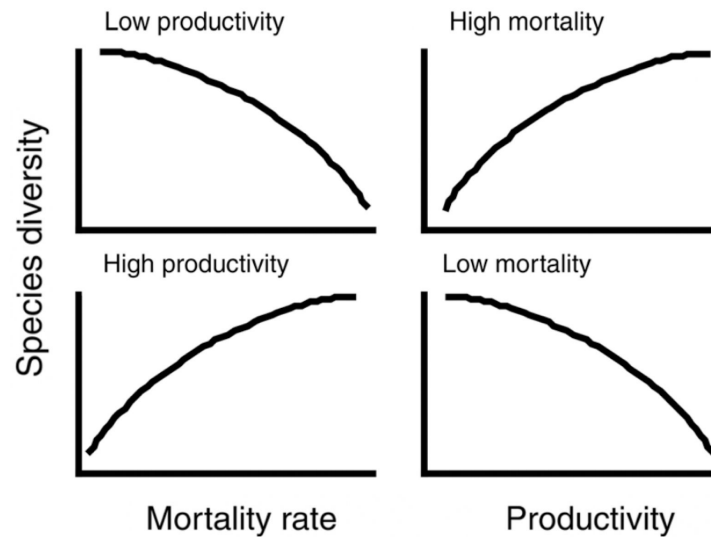
86. [1.5 pts] The diagram below contains examples of a well-studied ecological phenomenon. Each number associated with a line (e.g. 18a, 23b, 29+) represents a distinct community. All communities are two hectares in land size, and grazing intensity is measured against plant species richness.



Which of the following correctly matches the numbered community in the diagram to the phenomenon it demonstrates? Select ONE.

- a. 18d+, phototropic growth
- b. 19+, Allee effect
- c. 22, intermediate disturbance hypothesis
- d. 28a-, Red Queen hypothesis
- e. 28b, r/K selection theory

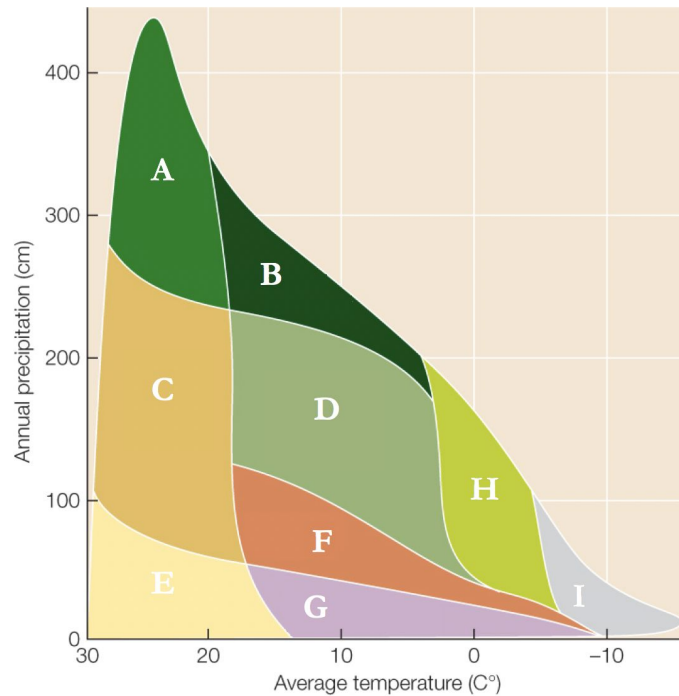
87. [1 pt] The graphs below represent the results of a study that measured mortality rate and productivity against species diversity in four equally abundant ecosystem types.



Which of the following statements are true? Select **ALL** that apply.

- a. Higher productivity ecosystems tend to have higher mortality rates.
- b. Highly diverse ecosystems tend to have higher mortality rates.
- c. Species diversity is positively correlated with productivity in all ecosystems.
- d. Ecosystems with low mortality rates and higher diversity tend to be less productive.
- e. Lower productivity ecosystems exhibit a strong intermediate disturbance effect.

88. [1.5 pts] The figure below shows average temperature and annual precipitation ranges for terrestrial biomes A-I.



Which of the following statements is true? Select **ALL** that apply.

- a. Mammals that live in Biome E are characterized by their small size, nocturnal lifestyle, and light-colored fur.
- b. Biome B's latitude is closer to the equator than Biome A's latitude.
- c. Large herbivores graze on grasses and forbs in Biome C.
- d. A permanently frozen layer of soil in Biome I restricts the growth of plant roots.
- e. Biome H includes the veldts of South Africa, the pampas of Argentina and Uruguay, and the prairies of North America.

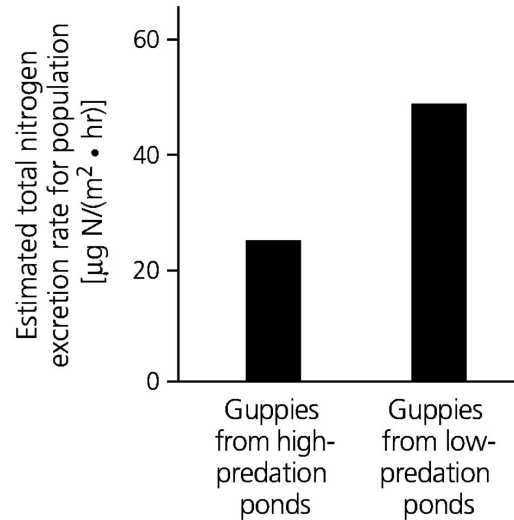
89. [1 pt] The population distribution of species depends on several factors. A certain waterbird species, of which a standard population is shown below, exhibits individual territoriality and high levels of intraspecific competition.



Which of the following best describes the waterbird species's population distribution?
Select ONE.

- a. Uniform
- b. Stabilizing
- c. Clumped
- d. Directional
- e. Random

90. [1.5 pts] Evolution and ecology are tightly interwoven processes. In a lab study assessing the ecological effects of predator selection, you measure the nitrogen excretion rate of guppy populations from high-predation versus low-predation ponds. The results of your study are shown below.



Which of the following reasonings best explains why lower-predation ponds show higher guppy nitrogen excretion rates? Select ONE.

- a. Lower predation allows guppies to produce more numerous offspring, which consume a larger volume of a pond's nitrogen-producing algae.
- b. Lower predation allows guppies to produce larger offspring, which in turn excrete more nitrogenous waste.
- c. Lower predation causes a bottom-up effect that allows primary producers to outcompete a pond's nitrogen-producing algae.
- d. Lower predation causes guppy populations to fall, allowing algae to produce more nitrogen.
- e. Lower predation causes guppy populations to rise, allowing guppies to outcompete other fish species that produce lower amounts of nitrogen.

Ethology

5 questions, 7.5 points

91. [1 pt] Which of the following examples most accurately demonstrates an instance of mate-choice copying? Select ONE.

- a. Female zebra finch birds are more likely to mate with ornamented male zebra finch birds if their father is not ornamented.
- b. Female zebra finch birds are more likely to mate with ornamented male zebra finch birds if their father is ornamented.
- c. Female guppies prefer to mate with male guppies that are seen being courted by other female guppies.
- d. Male stalk-flies challenge each other with their sexually-selected traits in order to determine which mates with a given female.
- e. Male jawfishes prefer to mate only with female jawfishes that have previously been with other mates.

92. [1.5 pts] You are studying the behavior of a mother hen and her chicks. A predator arrives and threatens the survival of the mother hen and her chicks. You know the mother hen is able to distract the predator for a certain period of time or, alternatively, escape the scene by herself to guarantee her own safety. Fortunately, you are an expert on kin selection. Which of the following predictions would you make? Select ONE.

- a. The mother hen will flee the scene by herself and leave behind her six chicks.
- b. Given that distracting the predator will cost the mother hen her own life, the mother hen will certainly distract the predator to guarantee the survival of two of her chicks.
- c. Given that distracting the predator will cost the mother hen her own life with probability 0.5, the mother hen will certainly distract the predator to guarantee the survival of one of her chicks.
- d. Given that distracting the predator will cost the mother hen her own life with probability $1/4$ and endow four chicks with $1/4$ chance of survival each, the mother hen will certainly distract the predator.
- e. Given that distracting the predator will cost the mother hen her own life with probability $1/6$ and endow six chicks with $1/8$ chance of survival each, the mother hen will certainly distract the predator.

93. [2 pts] Consider two individuals A and B. When A and B interact, they each have the opportunity to cooperate or not cooperate. We can model the payoffs for A and B with the payoff matrices below:

Payoff for A	A cooperates	A doesn't cooperate
B cooperates	3	5
B doesn't cooperate	0	1

Payoff for B	A cooperates	A doesn't cooperate
B cooperates	3	0
B doesn't cooperate	5	1

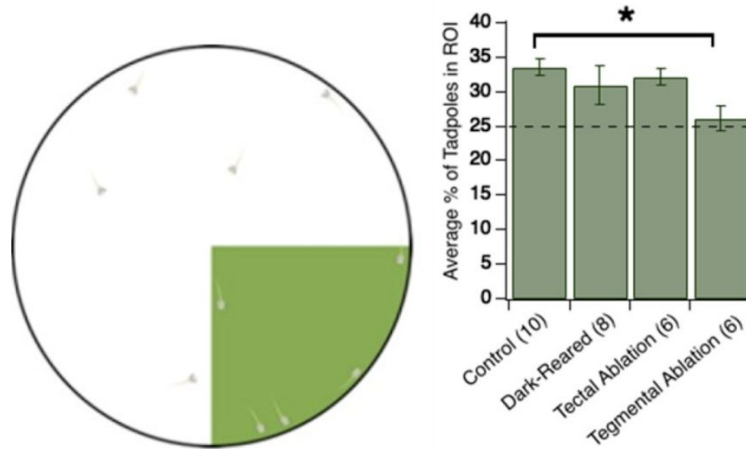
For example, when B cooperates and A doesn't cooperate, A gets a payoff of 5, and B gets a payoff of 1 (so A emerged better off from this interaction).

One strategy that an individual can use to choose to cooperate or not cooperate is the tit-for-tat model. When an individual A employs the tit-for-tat strategy, it first cooperates upon meeting another individual B. If the individual B also cooperates, the individual A will cooperate in its next interaction with B. However, if B doesn't cooperate, the individual A will not cooperate in its next interaction with B. This continues for however many interactions A and B have.

Suppose there exists a population of individuals that never cooperate when interacting. Call this population POP1. Consider an external population that employs the tit-for-tat model of cooperation. Call this external population POP2. Using these payoff matrices, which of the following is/are true? Select ALL that apply.

- a. In one interaction between an individual from POP1 and an individual from POP2, the individual from POP1 will always receive a higher payout.
- b. In two interactions between an individual from POP1 and an individual from POP2, the individual from POP1 will always receive a higher payout.
- c. In some number of interactions between an individual from POP1 and an individual from POP2, the individual from POP1 may not always receive a higher payout.
- d. Considering these payoffs as relative fitnesses, three POP2 individuals can successfully invade a population of 1000 POP1 individuals.
- e. Considering these payoffs as relative fitnesses, POP2 can successfully invade POP1 if the population size of POP2 is the same as the size of POP1.

94. [1.5 pts] Tadpoles were placed in a white petri dish in which one quarter of the dish (the region of interest, ROI) was illuminated with a green color. Four groups of tadpoles that were either raised in the dark (dark-reared), had their tectum removed (tectal ablation), had their tegmentum removed (tegmental ablation), or were raised normally (control) were placed into the petri dish, and the percentage of tadpoles in the green ROI after one minute was measured. From this data, what can you conclude? Note: an asterisk represents a significance difference ($p < 0.05$). Select ONE.

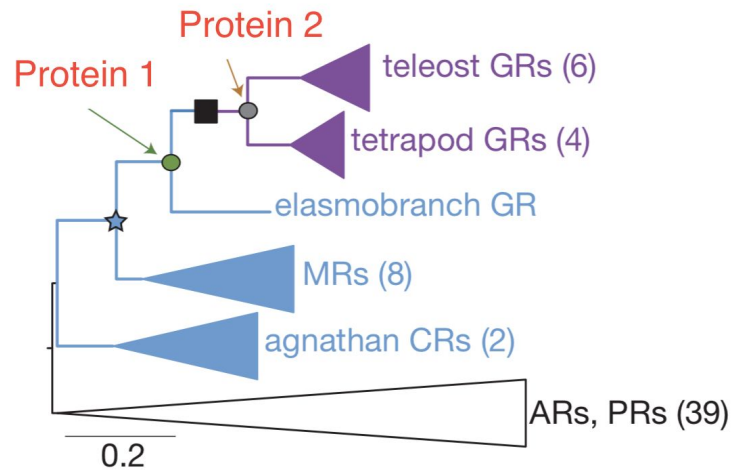


- The control group tadpoles spent an equal amount of time in each quadrant of the petri dish
 - The tadpoles' color preference is not dependent on whether they were reared in the dark or not
 - The tadpoles' response to green light is an example of operant conditioning
 - Tectal and tegmental ablation eliminated the tadpoles' preference for the ROI
 - The color green may be associated with predators or other dangers in the tadpole's natural environment
95. [1.5 pts] Which of the following is an example of operant conditioning? Select ONE.
- Migratory birds start heading south if the temperature drops below a certain point
 - A rat presses a lever to stop receiving electric shocks
 - Since you always take your dog on a walk after work, she grabs her leash when she hears your car enter the driveway
 - A fox spends more time waiting outside a rabbit hole to catch the rabbit if there are very few rabbit holes outside
 - A bird feeds its chicks when they open their mouths and chirp

Biosystematics

5 questions, 7.5 points

96. [1.5 pts] Examine the following phylogenetic tree. Note that Protein 1 is an ancestral version of Protein 2.



Which of the following statements is/are true? Select ALL that apply.

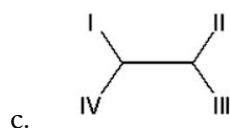
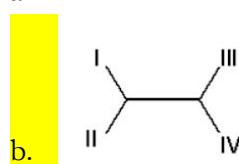
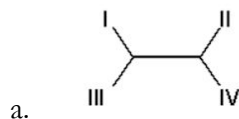
- a. Protein 2 is a derived trait of the tetrapods and teleosts.
- b. The branch lengths in this tree measure evolutionary time.
- c. The tetrapods and teleosts form a clade.
- d. The teleosts are more related to the tetrapods than to the elasmobranchs.
- e. The agnathans and elasmobranchs form a clade.

97. [1 pt] Your teacher asks you to capture a dragonfly, but you totally forget about the assignment until the day it is due! Unfortunately, you are unable to find any dragonflies, but you are able to find five animals, which you identify by Class. You also remember that your teacher will be grading you on how closely the DNA sequence of the organism you submit matches the reference DNA sequence of your assigned organism. Which of the following animals should you turn in (their Classes are listed below)? Select ONE.

- a. Arachnida
- b. Polychaeta
- c. Diplopoda
- d. Gastropoda
- e. Malacostraca

98. [2 pts] The chart below displays an DNA sequence alignment from four different species. If each “change” (deletion, substitution, etc.) occurs with the same probability, then which of the following unrooted trees most likely displays the evolutionary relationship between the four species? Select ONE.

	DNA Site									
Species	1	2	3	4	5	6	7	8	9	10
I	A	T	A	T	A	C	G	T	A	T
II	A	T	G	T	A	C	G	T	A	T
III	G	T	A	-	A	C	G	T	G	C
IV	G	C	G	T	A	T	G	C	A	C

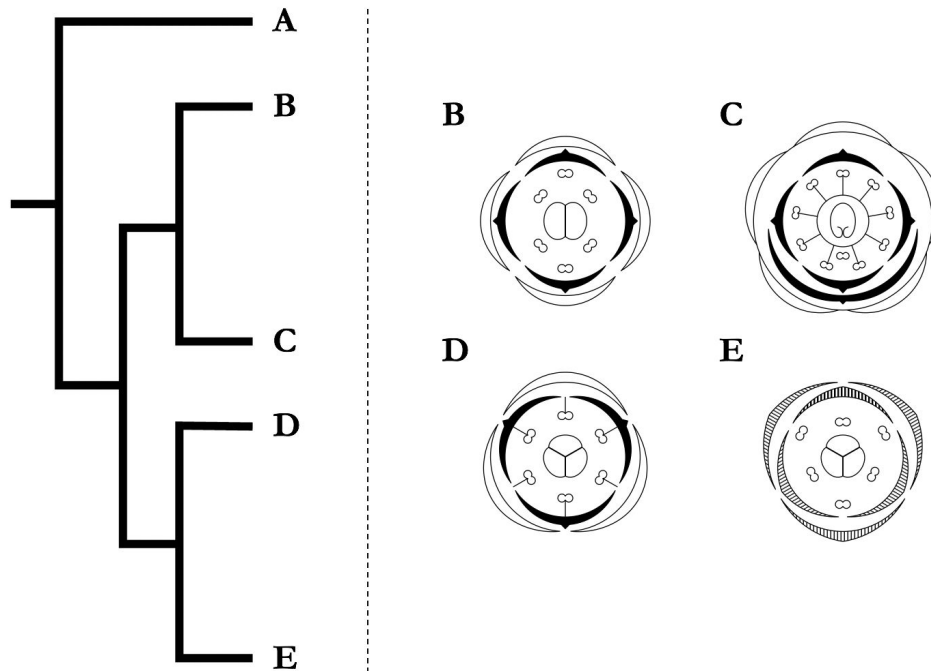


- d. Two of the trees above have the same probability of occurring
- e. All three trees above have the same probability of occurring

99. [1.5 pts] You are attempting to understand the phylogeny of photosynthetic organisms. A novel genus of cyanobacteria, *Gloeobacter*, has been discovered. In this genus, the light reactions do not occur on a thylakoid membrane, unlike most cyanobacteria; additionally, *Gloeobacter* cannot form filaments. Based on its morphology and cellular components, you decide to label it as an outgroup of cyanobacteria. Based on this information, which of the following is/are true? Select ALL that apply.

- a. The nitrogenase enzyme present in many cyanobacteria today is likely present in many *Gloeobacter* strains.
- b. Photosynthesis and respiration occur on the plasma membrane in *Gloeobacter*.
- c. Glycolytic enzymes are different between *Gloeobacter* and other cyanobacteria.
- d. *Gloeobacter* would be likely to have more diverse light-harvesting complex proteins than other cyanobacteria.
- e. Traits absent in *Gloeobacter* but present in other cyanobacteria evolved after the divergence of *Gloeobacter* and cyanobacteria.

100. [1.5 pts] The cladogram below shows the evolutionary relationship between plant species A-E. Corresponding floral diagrams characteristic of Species B-E are shown on the side. Species A is not a flowering plant species.



Which of the following statements are likely to be true? Select ALL that apply.

- a. Species B and E are both monocots.
- b. Species B belongs to the same family as selectively bred crops such as brussel sprouts, cabbage, kohlrabi, and kale.
- c. Species C is a legume, and its flowers are zygomorphic.
- d. Species D belongs to the same family as most grasses.
- e. Species A could belong to the magnoliids.

We look forward to seeing you at Finals!