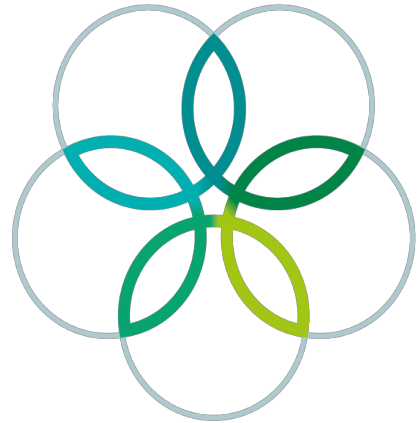
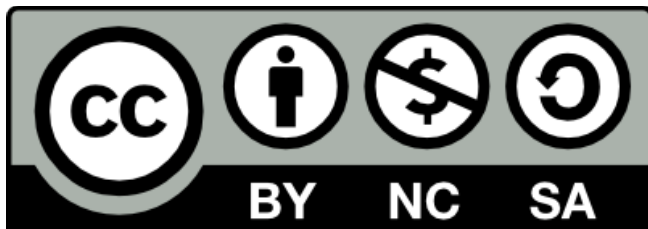


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Theoretical Exam - Part A



G0-1

English (Official)

General Instructions for Theory Part A

Date: July 11th, 2024

Time Allowed: 3 hours and 15 minutes (**NO additional time**)

The **Theory Part A exam** consists of **50** tasks across the following topics:

- **Biosystematics:** Q1-3
- **Cell and Molecular Biology:** Q4-12
- **Ecology:** Q13-17
- **Ethology:** Q18-19
- **Genetics & Evolution:** Q20-29
- **Plant Anatomy and Physiology:** Q30-37
- **Animal Anatomy and Physiology:** Q38-50

Supplementary figures are provided in the **Appendix**.

Each question is worth a maximum of 1.0 point. Marking is done based on the scheme below:					
Number of correctly identified statements	0	1	2	3	4
Points	0	0	0.2	0.6	1

Please keep in mind:

Instructions

You can use the question paper for your notes and rough work, we do not assess it.

An answer sheet is provided. **Only answers recorded on the answer sheet will be scored.** The sheet includes several fields that need to be filled out. Follow the instructions below for filling out the answer sheet:

In the "Last and First Name" field, write your last name (family name) and first name in English (if both do not fit, write only your last name).

In the "Country or Territory" field, write the country or territory you represent at the IBO in English.

In the "ID№" field, first enter the three digits of your personal ID number in the leftmost column (from top to bottom), then shade the corresponding digit in the row to the right of each digit of the ID number.

The largest field, "Answers," contains 50 questions, each with four statements labelled A, B, C, and D. Each statement has two squares: the "T" square indicates true, and the "F" square indicates false.

Ensure that the squares in the "ID№" and "Answers" fields are completely shaded with no unshaded areas remaining and without going outside the boundaries. Marks like "+", "x", checkmarks, or circles will not be read. Black squares must be shaded with a black pen (using a red pen or pencil is strictly prohibited).

Theoretical Exam - Part A



G0-2

English (Official)

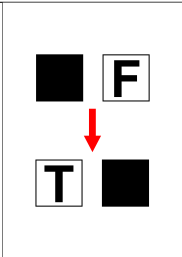
Do NOT fill out the "charge person" field and do NOT shade any fields that are not specified above. Black squares in the corners SHOULD NOT be shaded/corrected as it will interfere with the scanning process.

Communication with Organizers

You are provided with four types of cards for assistance during the exam:

- **Drinking Water (Blue):** Raise this card if you need water.
- **Washroom (Yellow):** Raise this card if you need to use the washroom.
- **Correction (White):** Raise this card if you made a mistake on your answer sheet and want to fix it.
- **Other Queries (Red):** Raise this card if you have any other questions.

If you make a mistake on your answer sheet, use the "Correction (White)" card to request a correction pen. Using the correction pen, recolor the wrongly shaded area into white without going outside the boundaries. **You cannot ask for correction in the last 10 minutes.** (Note: Overuse of the correction pen may cause scanning errors, **try to put in the answers once you are fully confident**)

Drinking water	Washroom	Correction	Other queries
			

During the Exam

At the beginning of the exam, a whistle signal will let you know to open the exam papers and start writing.

15 minutes before the end, please start filling out the answer sheet if you have not already. We **do not provide** extra time to put your answers on the answer sheet.

At the end of the exam, a whistle signal will indicate when to stop writing and put down your pen **immediately**.

Continuing to write after the whistle signal will result in **disqualification**.

No materials, papers, or equipment should be taken out of the examination room.

Theoretical Exam - Part A

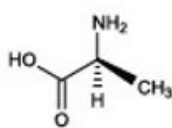


G8-1

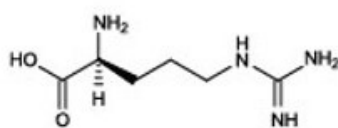
English (Official)

Appendix

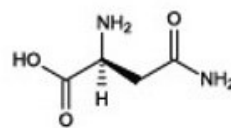
Amino acid structures with abbreviations: **G**-glycine, **A**-alanine, **S**-Serine, **T**-Threonine, **C**-Cysteine, **V**-Valine, **L**-Leucine, **I**-Isoleucine, **M**-Methionine, **P**-Proline, **F**-Phenylalanine, **Y**-Tyrosine, **W**-Tryptophan, **D**-Aspartic acid, **E**-Glutamic acid, **N**-Asparagine, **Q**-Glutamine, **H**-Histidine, **K**-Lysine, **R**-Arginine



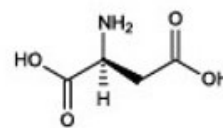
(Ala, A)



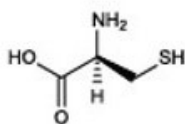
(Arg, R)



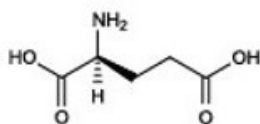
(Asn, N)



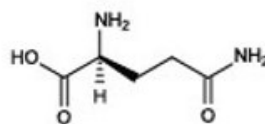
(Asp, D)



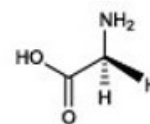
(Cys, C)



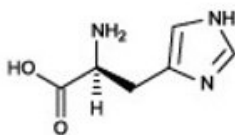
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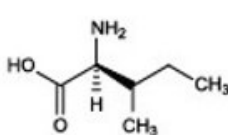
(Gln, Q)



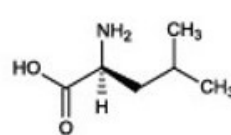
(Gly, G)



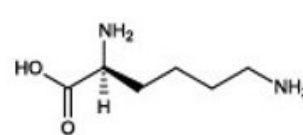
(His, H)



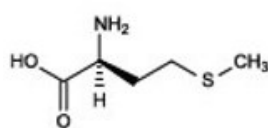
(Ile, I)



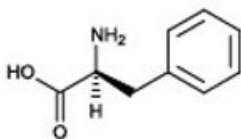
(Leu, L)



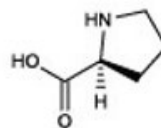
(Lys, K)



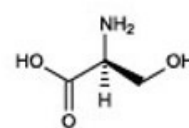
(Met, M)



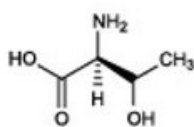
(Phe, F)



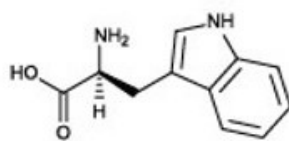
(Pro, P)



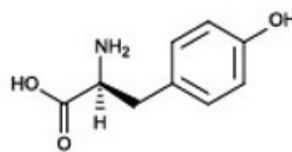
(Ser, S)



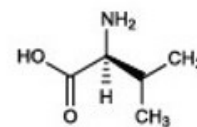
(Thr, T)



(Trp, W)



(Tyr, Y)



(Val, V)

Theoretical Exam - Part A



G8-2

English (Official)

Codon table for Amino acids:

		Second letter				
		U	C	A	G	
First letter	U	UUU } Phe UUC } UUA } Leu UUG }	UCU } UCC } Ser UCA } UCG }	UAU } Tyr UAC } UAA Stop UAG Stop	UGU } Cys UGC } UGA Stop UGG Trp	U C A G
	C	CUU } CUC } Leu CUA } CUG }	CCU } CCC } Pro CCA } CCG }	CAU } His CAC } CAA } Gln CAG }	CGU } CGC } Arg CGA } CGG }	U C A G
	A	AUU } AUC } Ile AUA } AUG Met	ACU } ACC } Thr ACA } ACG }	AAU } Asn AAC } AAA } Lys AAG }	AGU } Ser AGC } AGA } Arg AGG }	U C A G
	G	GUU } GUC } Val GUA } GUG }	GCU } GCC } Ala GCA } GCG }	GAU } Asp GAC } GAA } Glu GAG }	GGU } GGC } Gly GGA } GGG }	U C A G
						Third letter

Theoretical Exam - Part A



Q1-1

English (Official)

Biosystematics

1

Kazakhstan boasts a rich ecosystem harboring numerous species of tulips, some of which are direct ancestors to many modern cultivated varieties. These tulips exhibit a diverse range of morphological traits, although not all of these traits are reliable indicators of species identification.

In Table 1 below, we outline five distinct types of tulips and their variations across five characteristics (A-E), typically utilized in the classification of tulip types.

	<i>Tulipa lemmersii</i>	<i>Tulipa salsola</i>	<i>Tulipa altacia</i>	<i>Tulipa bifloroformis</i>	<i>Tulipa borszczowii</i>
					
A	X	✓	X	✓	X
B	1	1	1	2(+)	1
C	X	X	✓	X	✓
D	3(+)	2	3(+)	2	3(+)
E	Y	Y	Y	Y	K

Table 1. Morphological comparisons; A - presence/absence of hairs on the stamen, B - number of flowers (2+) = 2 or more, C - presence/absence of a dense layer of hairs on the bulbs, D - number of leaves, E - color of the stamen filament, Y - yellow, K - black.

It's worth noting that *T. borszczowii* has the same features as the common ancestor among these tulip species.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. In a phylogenetic tree constructed using maximum parsimony, the species *T. lemmersii*, *T. salsola*, and *T. bifloroformis* are expected to constitute a polyphyletic group.

B. The maximum parsimony tree contains at least one character reversal.

C. All plants within the genus *Tulipa* share the characteristic of having leaves with either arcuate or parallel veins.

D. According to the data, the presence of two or more flowers is the most recently evolved characteristic compared to the others.

Theoretical Exam - Part A



Q1-2

English (Official)

2

You are given five species of birds from the Strigiformes order (Owls), commonly found in Kazakhstan (Figure 1A). However, the genera to which these species belong are unknown to you. To ascertain this, you were provided with information depicted in the figures below.

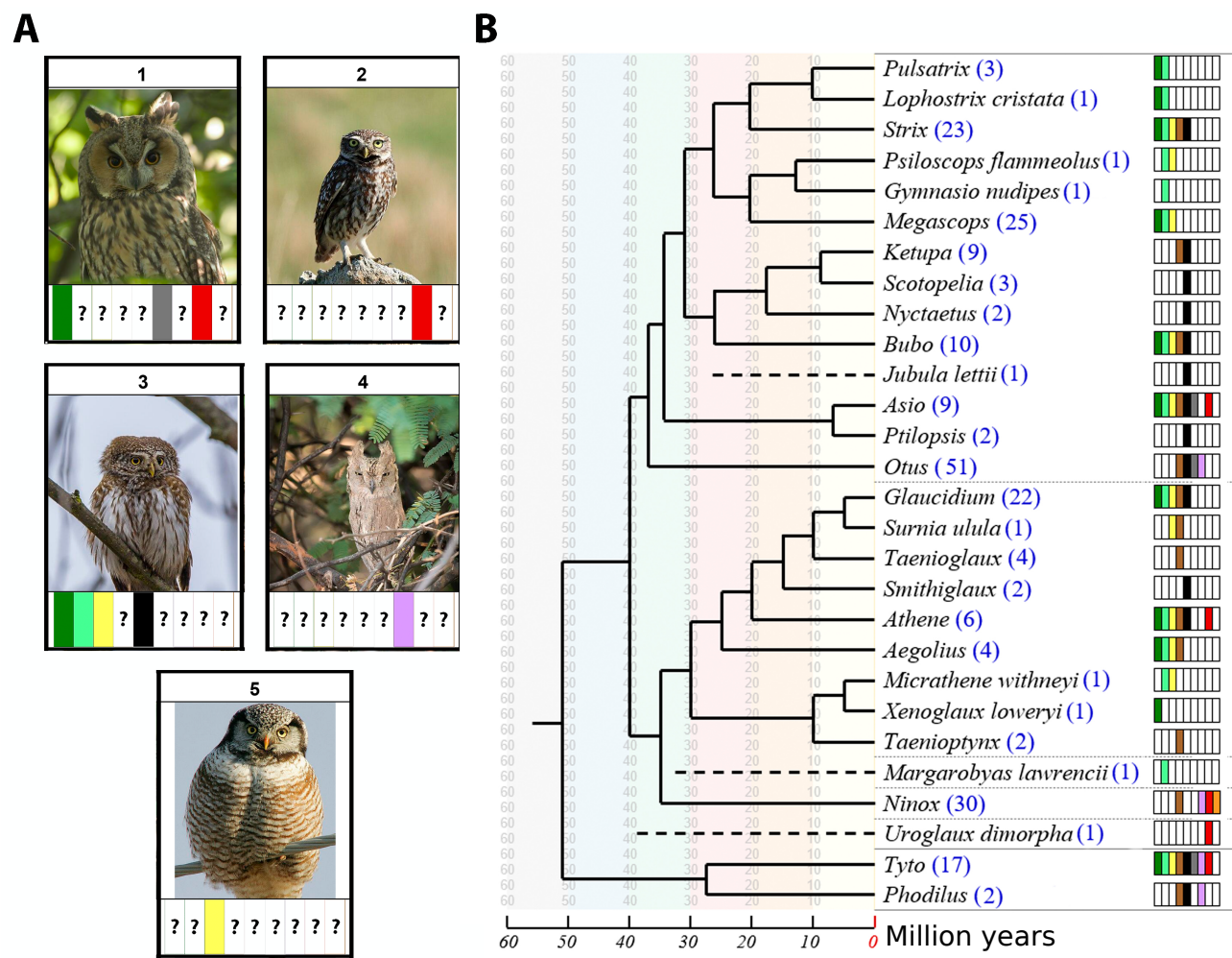


Figure 1. **A** Five bird species; the bottom row in each box represents the partial list of the birds' inhabiting areas (refer to Figure 2). **B** Phylogenetic tree of the Strigiformes order with their full inhabiting area lists. The number of species that make up the corresponding genus is indicated in parentheses.



Figure 2. Area distribution key; each rectangle corresponds to a certain area.

It is also known that:

- Species 3 and 5 share the most recent common ancestor that lived 5 million years ago.
- Species 2 and 3 share the most recent common ancestor that lived 20 million years ago.
- Species 5 and 4 share the most recent common ancestor that lived 40 million years ago.
- The genus to which species 1 belongs has never been found in the Philippines.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** One of the five listed species is the only representative of its genus.
- B.** Constructing a phylogenetic tree using this data reveals that species 1 and 4 are the second most closely related among the five species.
- C.** Some of the five given species belong to the same genus.
- D.** A migration (in terms of species dispersal) from America to Africa and Eurasia is a more parsimonious explanation for the geographic distribution of *Strix* compared to a migration in the opposite direction.

Theoretical Exam - Part A



Q1-4

English (Official)

3

Yerzhan studies the evolution of four closely related bacterial strains (A, B, C, D), focusing on RNA polymerase subunit β and transposase. He reconstructed phylogenetic trees for the two corresponding genes that code for these proteins (Figure 1X,Y) using the alignment of four sequences (representative snapshot is shown on Figure 2) and the most parsimonious solution. He rooted both phylogenies using the D strain as an outgroup. Unfortunately, he realized that he forgot to properly label the datasets. Consequently, he began comparing these phylogenetic trees to the reference phylogenetic tree reconstructed from genes of ribosomal proteins (Figure 1Z).

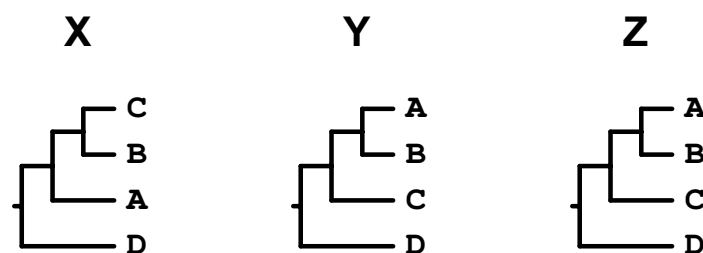


Figure 1. Phylogenetic trees reconstructed from RNA polymerase subunit β (X or Y), transposase (X or Y) and reference genes of ribosomal proteins (Z).

	I		II
A	GGACT	A	CAGTC
B	CCATT	B	GCGTC
C	GCATA	C	GCACA
D	CGACT	D	GGCCA

Figure 2. Alignments of representative regions of two genes from four bacteria strains (A-D)

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A. Phylogenetic tree X was reconstructed from the alignment I.
- B. In the Alignment I, 4 out of 5 positions are useful for determining tree's topology.
- C. Phylogenetic tree X was reconstructed from the RNA polymerase subunit β .
- D. Using species D as an outgroup, there are in total two possible phylogenetic tree topologies for the four species A-D.

Cell and Molecular Biology

4

The extracellular pH of normal tissues is typically between 7.35 and 7.45. Meanwhile, in the tumor microenvironment, extracellular pH is mildly acidic in the range of 6.5–6.9. Figure 1B provides an overview of the average extracellular pH values observed in different tumor types compared to their respective normal cells. Cancer cells also exhibit changes in the oxygen consumption rates (OCR). This phenomenon is demonstrated in Figure 1A by comparing the OCR of normal and cancer cells from three patients.

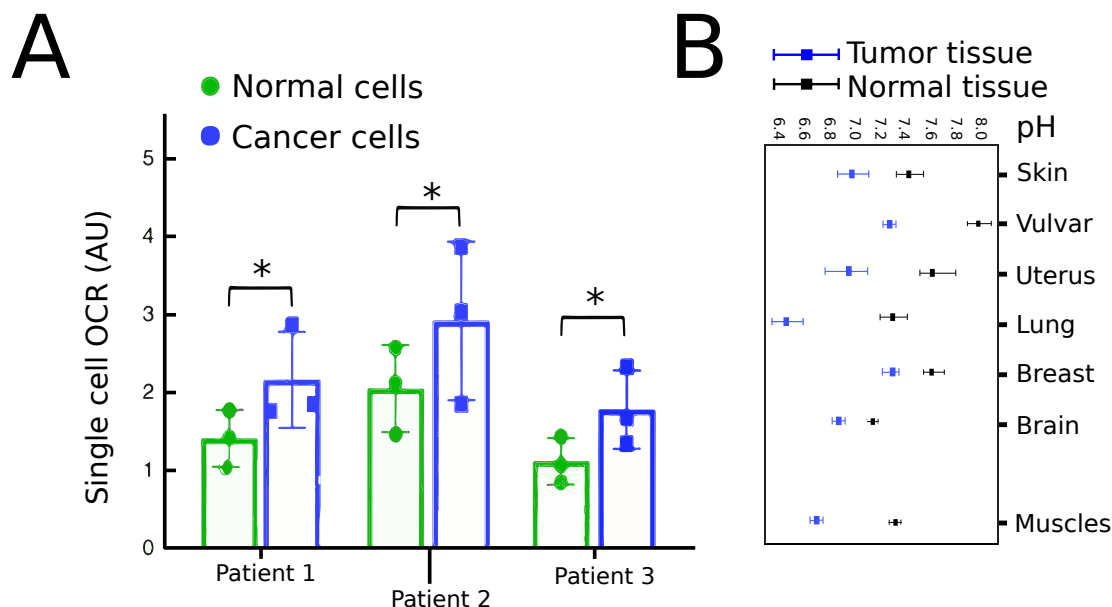


Figure 1. **A** Oxygen consumption rates (OCR) in arbitrary units (AU) of normal and cancer cells. **B** Extracellular pH of normal tissue and corresponding tumor tissue. Asterisk indicates a significant difference.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. Difference in oxygen consumption between cancerous and normal cells indicates that tumor cells exhibit decreased metabolic rate.

B. Differences in extracellular pH values can be explained by the altered ratio of glucose fermentation to oxidative phosphorylation in cancer cells compared to normal ones.

C. The tumor microenvironment is typically hyperoxic due to elevated oxygen consumption by cancer cells.

D. The cancer cells of patient 3 are more heterogeneous compared to the cancer cells of the other two patients.

5

Mutagenesis was performed to determine the effect of single mutations in the binding site of an antibody. The mutants were analyzed for binding to four cardiac glycoside molecules: digoxin, digitoxin, digoxigenin, and ouabain. The binding properties of mutated antibodies were tested by ELISA, a technique that relies on enzyme-linked antibodies to detect target antigens. After the antibody binds to the antigen (in our case, glycoside), the enzyme linked to the antibody catalyzes the added substrate, leading to a color change that can be measured by spectrophotometry at 405 nm. The following heatmaps represent the ELISA results based on the position of change and the amino acid to which wild-type amino acid was mutated.

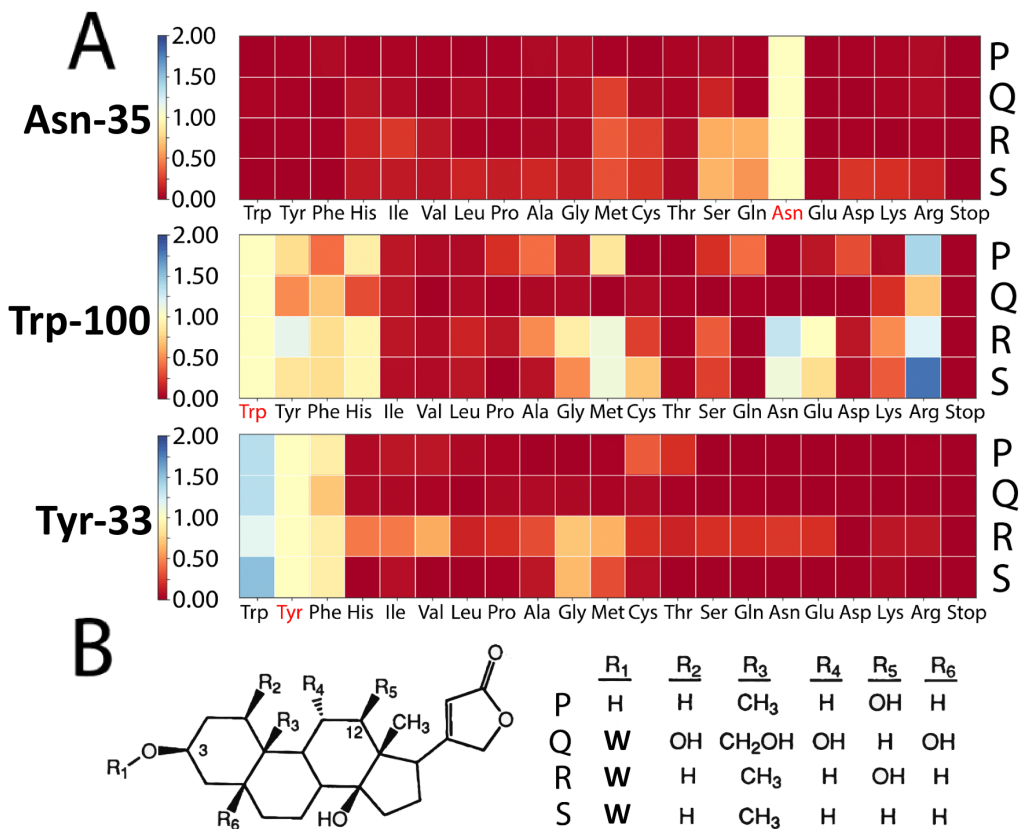


Figure 1. **A** Binding data of antibodies mutated in the positions described in the figure to the four glycosides. The absorbance, which correlates to the binding strength of digoxigenin (P), ouabain (Q), digoxin (R), and digitoxin (S) to the mutated antibodies, was linearly scaled to that of the wild-type (labeled in red) which was assigned a value of 1.0 (labels of glycosides P, Q, R, and S should not be confused with the one-letter codes of amino acids). **B** Differences in the structure of digoxin (R) and its three analogs. W - sugars.



On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. The strongest binding in position Tyr-33 was for substitution by aromatic amino acids.

B. In all shown amino acid positions, at least one substitution improves the antibody affinity.

C. Antibody with double substitution Tyr-33-Trp and Trp-100-Arg probably could be used in cardiac glycoside detection systems.

D. Sugar moieties appear to play a role in the affinities of antibodies to cardiac glycoside molecules.

6

The bonds between the central carbon atom and attached groups in peptides can rotate freely. The rotation angles of the N-C α and C α -C bonds are called Φ and ψ angles, respectively. To measure the ψ angle, first draw the C α -C bond horizontally so that the N group is at 0 degrees (in the same plane as the C α -C bond). Then rotate the distal N group around the C α -C bond until the structure matches the structure that you aim to measure as shown in Figure 1C. For the Φ angle, place the N-C α bond horizontally and rotate the distal C group. The Ramachandran plot visually represents the combinations of Φ and ψ angles in a peptide backbone (Figure 1B).

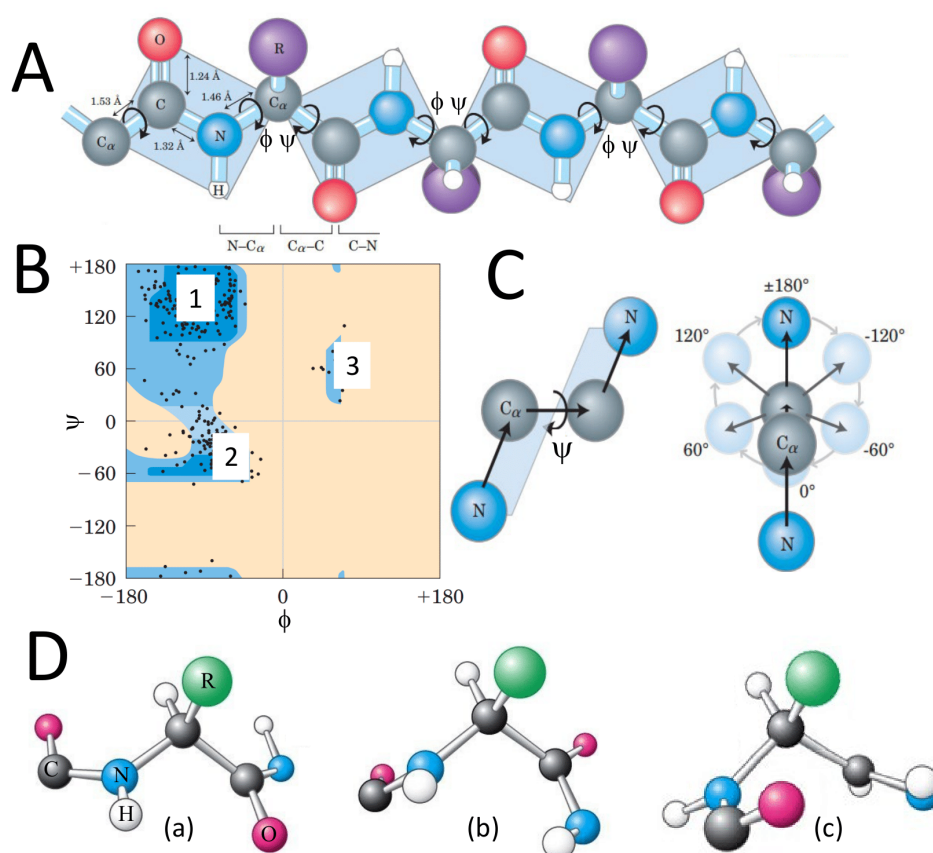


Figure 1. **A** Part of the peptide with shown Φ and ψ angles. **B** The Ramachandran plot with the values of Φ and ψ angles for all the amino acid residues except Gly in the rabbit's pyruvate kinase. **C** The ψ angle values are created by the rotation. **D** Three structures of amino acids' residues.



On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** The structure (a) in Figure 1D is located in Region 2 in Figure 1B.
- B.** The structure (b) in Figure 1D is located in Region 3 in Figure 1B.
- C.** The structure (c) in Figure 1D is uncommon in rabbit's pyruvate kinase.
- D.** Amino acids, other than glycine, with 0 degrees of both Φ and ψ angles do not occur in rabbit's pyruvate kinase.

7

The Pentose Phosphate Pathway (PPP) is a metabolic pathway occurring in the cytoplasm that mainly generates NADPH and ribose 5-phosphate. NADPH is used for the reduction of reactive oxygen species (ROS) such as hydrogen peroxide. PPP has oxidative and non-oxidative phases, which are irreversible and reversible, respectively.

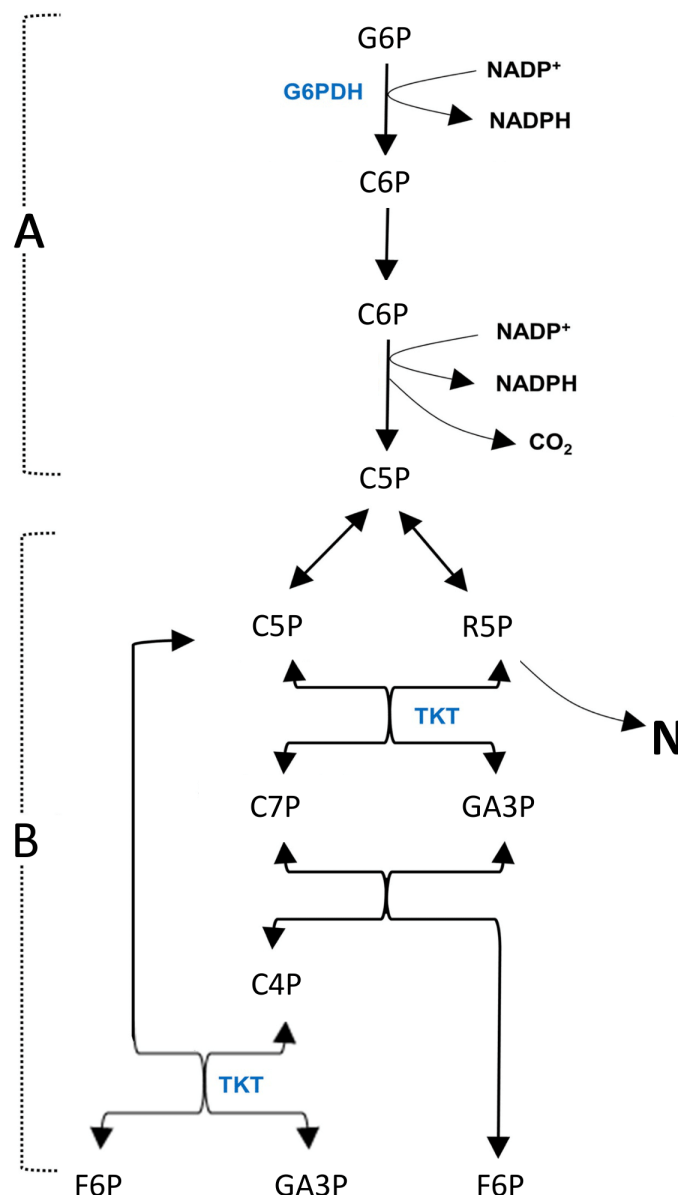


Figure 1. **A** Oxidative. **B** Non-oxidative. G6P – glucose 6-phosphate, GA3P – glyceraldehyde 3-phosphate, F6P – fructose 6-phosphate, R5P – ribose 5-phosphate, G6PDH – glucose 6-phosphate dehydrogenase, TKT – transketolase, N – nucleotides. CXP – other intermediates where X is the position of phosphorylated carbon. Note that all intermediates of PPP are phosphorylated on the last carbon.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. In actively dividing cells, the reactions occurring before the first TKT-catalyzed reaction are more active than those occurring later.

B. TKT catalyzes a reaction that transfers a one-carbon fragment.

C. Deficiency of G6PDH activity will reduce the level of available NADPH in red blood cells.

D. For each molecule of G6P, there will be two molecules of F6P produced through both phases.

8

Certain loci in the genome are influenced by epigenetic modifications, but understanding their precise mechanisms remains challenging. The IGF2-H19 locus serves as a well-known example, regulated by the methylation state of the imprinting control region (ICR). In addition to the two genes, this locus contains one enhancer and four CTCF-binding sites (CTCF is a DNA-binding protein), one of which serves as an ICR. A proposed model suggests that the spatial interaction among these elements underlies the regulatory mechanism governing the expression of IGF2 and H19. CTCF binding does not interrupt with the promoter function.

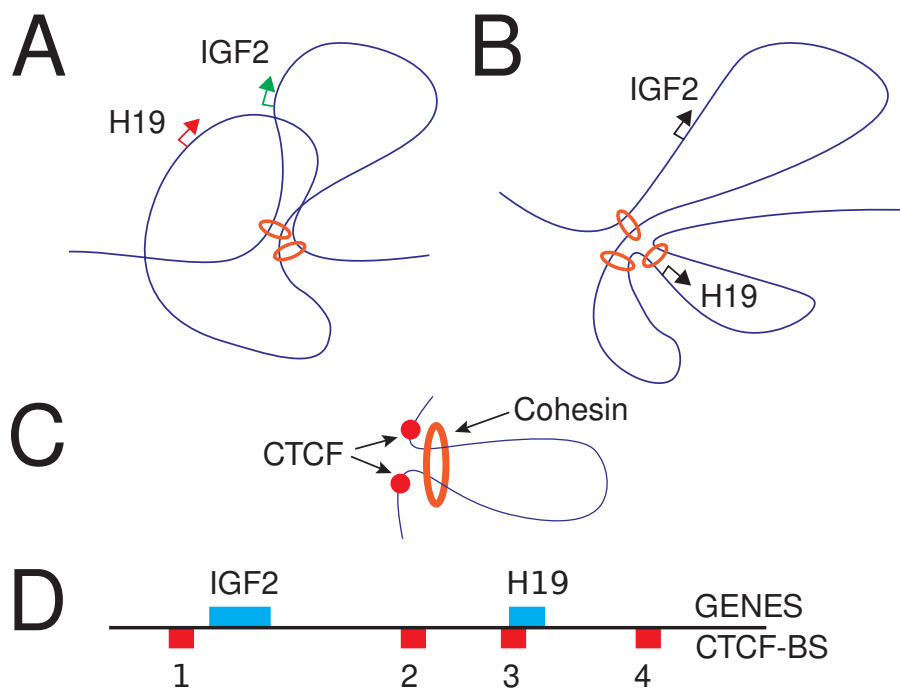


Figure 1. **A** Paternal chromosome, IGF2 active (green arrow) and H19 inactive (red arrow). **B** Maternal chromosome, IGF2 and H19 basal expression (black arrows). Note that diagrams A and B reflects real physical distances and that intersection of two blue lines (representing DNA) reflects very close physical proximity of two DNA strands. **C** DNA loop formed by CTCF and cohesin. **D** IGF2-H19 locus with CTCF-binding sites 1-4 (CTCF-BS).

Theoretical Exam - Part A



Q2-9

English (Official)

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** One CTCF-binding site can be involved in the formation of only one DNA loop.
- B.** ICR overlaps with CTCF binding site 2.
- C.** The enhancer is located between CTCF binding sites 3 and 4.
- D.** ICR methylation directly affects the expression of H19, independent of the enhancer.

9

Cryo-EM is a modern structural study technique that works by averaging multiple low-quality electron micrographs, cryo-EM generates high-quality structural maps. It offers flexibility by accommodating various molecular sizes and capturing multiple conformations. The structure and mechanism of ATAD1, a mitochondrial homohexamer protein, were resolved using cryo-EM. The protein's function was then determined using the structural data and fluorescent assays.

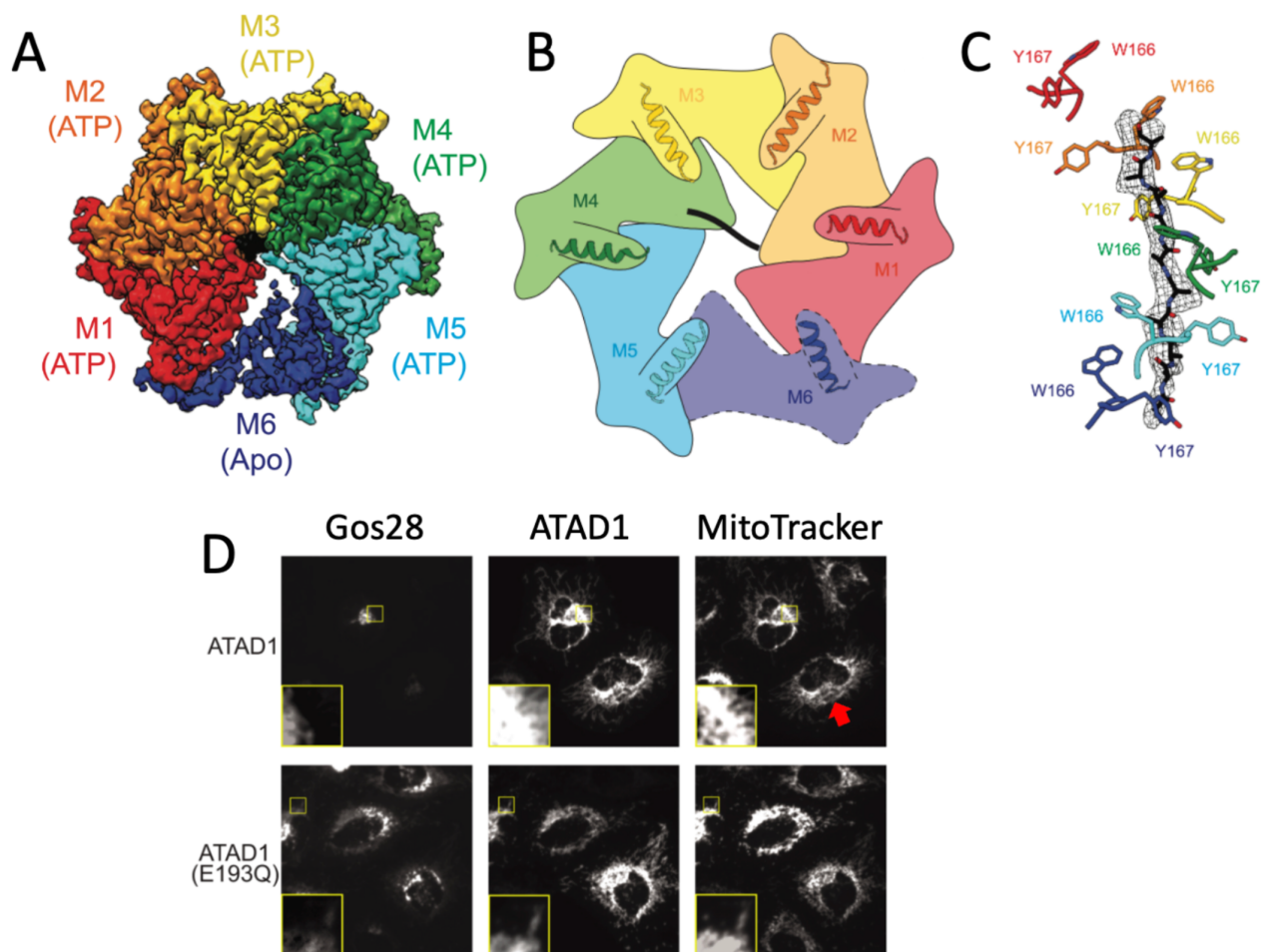


Figure 1. **A** Density map of the average of all conformations obtained by electron microscopy. **B** Top view of the molecular model of ATAD1 hexamer emphasizing C-terminal alpha-helices, with a black curve representing the polypeptide chain substrate. **C** The structure of the central pore with its substrate (black) and all interacting amino acids (colored residues). **D** Fluorescent microscopy assay for wild-type ATAD1 and with mutation E193Q (at position 193, Glu → Gln), Gos28 is the hypothetical target, MitoTracker is a mitochondrial fluorescent marker, the red arrow points to one mitochondrion.



On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Given that the density map contains an unclear M6 subunit, at any moment only one of the ATAD1 subunits is flexible.
- B.** C-terminal alpha helices shown on the molecular model are made entirely from hydrophobic amino acids.
- C.** Change of charge due to mutation E193Q affects the physical interaction of position 193 with the substrate.
- D.** ATAD1 translocates proteins mislocalized into the matrix of the mitochondria.

10

Magnetotactic bacteria have magnetosomes (magnetite crystals with a lipid membrane) arranged in a line, helping them find water with suitable oxygen levels in the oxic-anoxic transition zone (OATZ in Figure 1B). These bacteria are classified into two types: polar, which align their body orientation with the magnetic field, and axial, which can have two orientations along the magnetic field axis. In the Earth's Northern and Southern hemispheres, polar bacteria magnetosomes have opposite polarities. To stay in the OATZ, polar bacteria change the rotation direction of their flagella based on oxygen concentration.

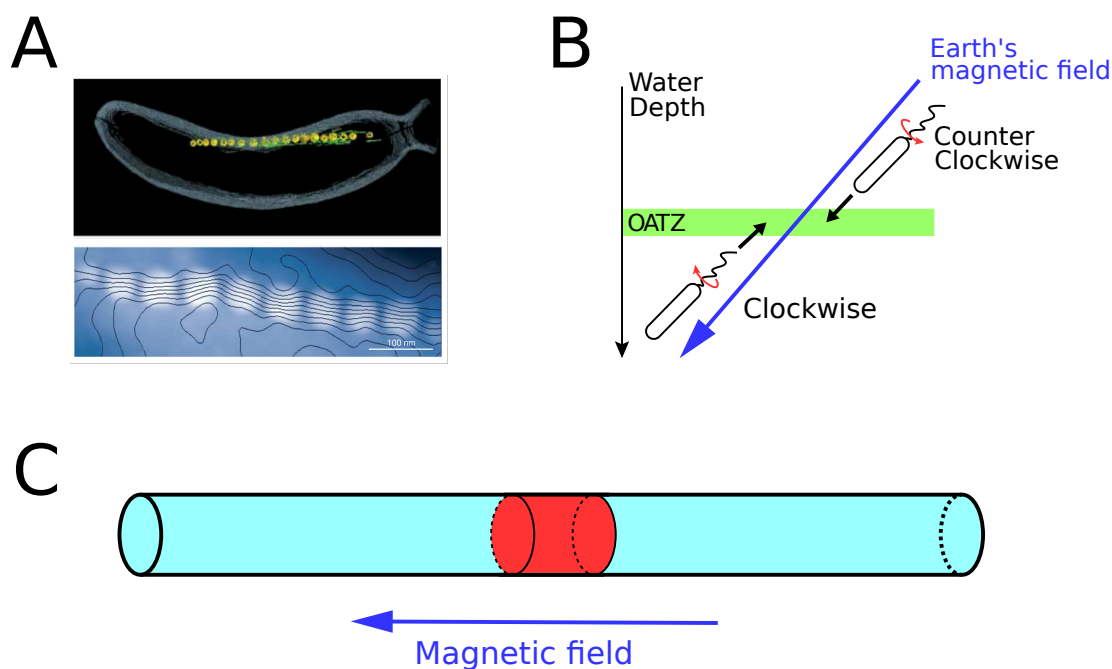


Figure 1. **A** Magnetotactic bacteria with labeled magnetosomes, the lower image shows the magnetic field generated. **B** Northern hemisphere polar bacteria in water, OATZ - suitable oxygen level. **C** Experimental setup: water-filled tube with two openings in a magnetic field. Bacteria start in the anoxic zone (red).

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Magnetosomes help bacteria find the shortest path toward OATZ.
- B.** Polar bacteria from the southern hemisphere should have a clockwise flagella rotation when above OATZ.
- C.** Axial magnetotactic bacteria will form 2 distinct bands in experimental setup.
- D.** Polar magnetotactic bacteria from the southern hemisphere will start a counterclockwise rotation of flagella when placed into experimental setup.

11

Directed evolution is a process that mimics natural selection by artificially applying selective pressure to organisms to screen and select for a desired phenotype. Directed evolution can be employed in protein engineering.

The *Escherichia coli* AL strain was engineered by deleting specific pathways that regenerate NAD^+ (Figure 1). NAD^+ regeneration can be restored by introducing a foreign enzyme, referred to as Enzyme D, which converts an exogenous substrate, not naturally connected to the native metabolic network, into a non-toxic product using NADH as a cofactor. A library comprising randomized mutants of Enzyme D is introduced into the engineered *E. coli* AL strain.

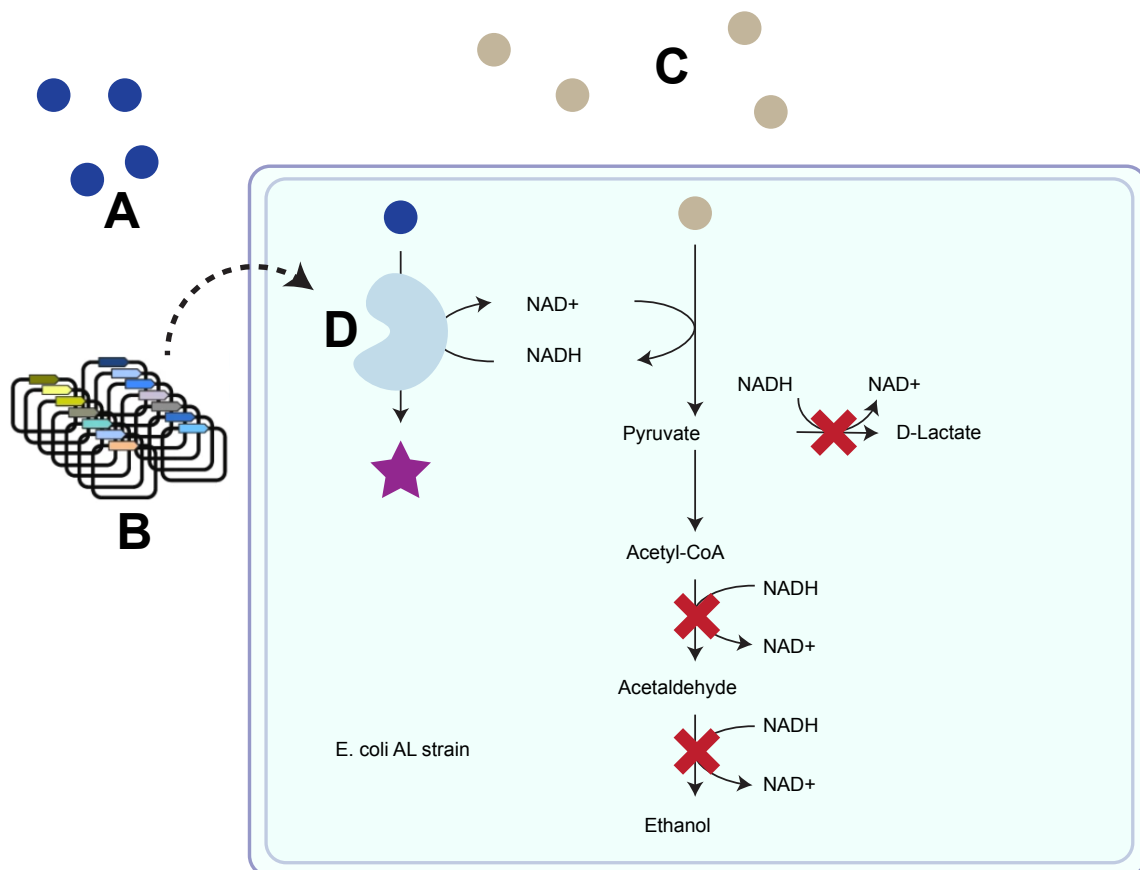


Figure 1. **A:** exogenous substrate present in large intestine; **B:** library variants of enzyme D; **C:** carbon source; **D:** enzyme D

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. Library construction is not required for directed evolution, as Enzyme D can mutate after selective pressure is applied.

B. Enzyme D is under selective pressure only when the strain AL is growing under aerobic conditions.

C. This method of directed evolution allows for differentiating between variants of NADH-dependent enzymes with low activity or high activity, in order to select the variants with the highest activity.

D. *E. coli* AL strains with variants showing higher activity of Enzyme D have a better chance of survival in the human large intestine.

12

A terminal cervical cancer patient arrived at the emergency room and received intravenous therapy and oxygen, but her condition did not improve. Medical personnel noticed a garlic-like odor, typically caused by sulfur-containing substances, emanating from her mouth, and white crystals formed in a blood sample taken from her. Subsequently, the medical staff began losing consciousness and having convulsions.

This 1994 incident at Riverside General Hospital was initially thought to be mass hysteria, later suspicion fell on DMSO_4 : prior to admission, the patient had applied excessive amounts of DMSO-based ointments for analgesic purposes. While DMSO itself is non-toxic to humans, DMSO_4 is classified as a warfare agent. It rapidly undergoes the following reaction:

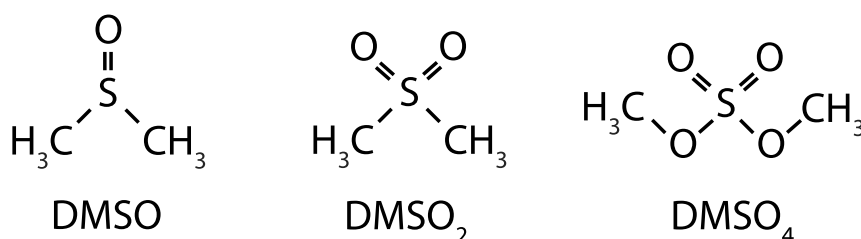


Figure 1. DMSO , DMSO_2 , and DMSO_4 structures. DMSO_4 can be produced by successive oxidation reactions of DMSO and DMSO_2 .

Compound	DMSO	DMSO_2	DMSO_4
Enthalpy of formation (kJ/mol)	-150	-373	-687
Solubility in water (g/L)	≥ 150	150	28

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. Out of the three involved substances, DMSO_2 most probably accounts for crystals in the collected blood.

B. DMSO can increase the rate of absorption of compounds through biological membranes.

C. The enthalpies of formation indicate that DMSO can rapidly change into DMSO_2 and then into DMSO_4 by being exposed to oxygen at room temperature.

D. Cervical cancer metastases in the ureters have likely restricted the only pathway of eliminating DMSO and its derivatives.

Ecology

13

Legumes can fix nitrogen from the air. Anecdotal evidence showed industrial pollution with nitrogen and other macronutrients making legumes less fit for nitrogen-poor steppes and other grasslands, which make up half of Kazakhstan.

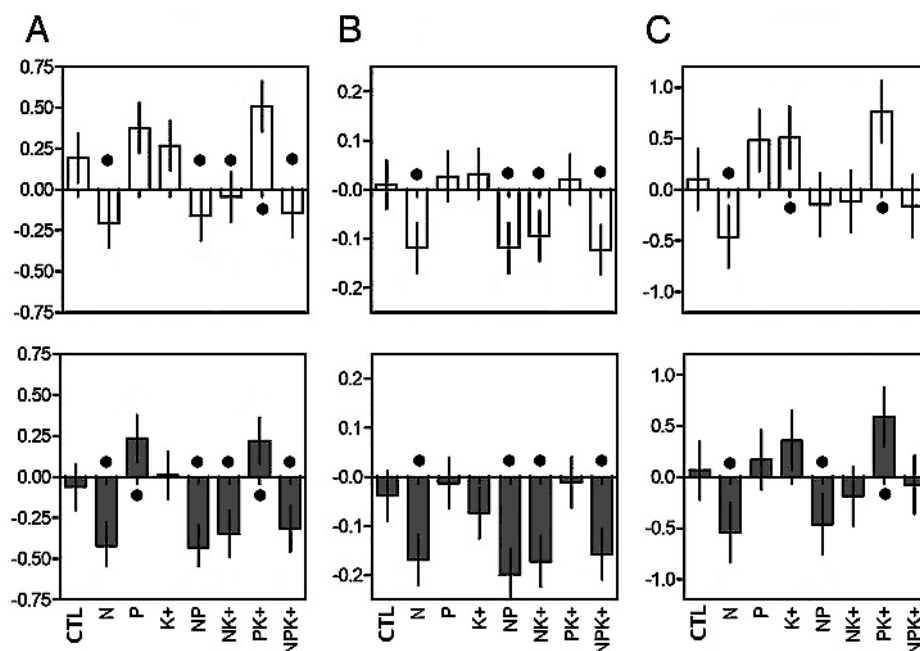


Figure 1. The graph shows the effect of increased nutrients on the legumes in steppe field plot study. They had control soil (CTL), as well as soil enriched with N (nitrogen), P (phosphorus), K⁺ (potassium), and combinations of these elements. The top row is the normalized change (NC) after 3 years of treatment, and the bottom row is the NC after 6 years of treatment. Letters represent NC in A) legume cover B) species richness C) biomass of legumes. Black dots represent a statistically significant difference from control. Whiskers stand for the Standard Error of Mean (SEM)

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Potassium coupled with nitrogen has a non-significant effect on legume cover.
- B.** Legume biomass has the opposite response to changes in soil nutrients after 3 years and 6 years of treatment.
- C.** The graphs support steppe being, in general, a nitrogen-limited ecosystem.
- D.** In analogous graphs for non-nitrogen fixing plants, the NC values for nitrogen-enriched soil will be positive.

14

The latitudinal diversity gradient describes a common pattern in the species richness seen in most groups of organisms whereby there are less species in the temperate regions than in the tropics. Species richness is lowest at the poles and highest on the equator. The ubiquity of this pattern suggests the possibility of a single general explanation but our understanding of this pattern is incomplete. The current latitudinal zones arose approximately 45 million years ago, after a period in which the Earth was primarily tropical. The following three hypotheses (Figure 1A-C) could possibly explain this gradient:

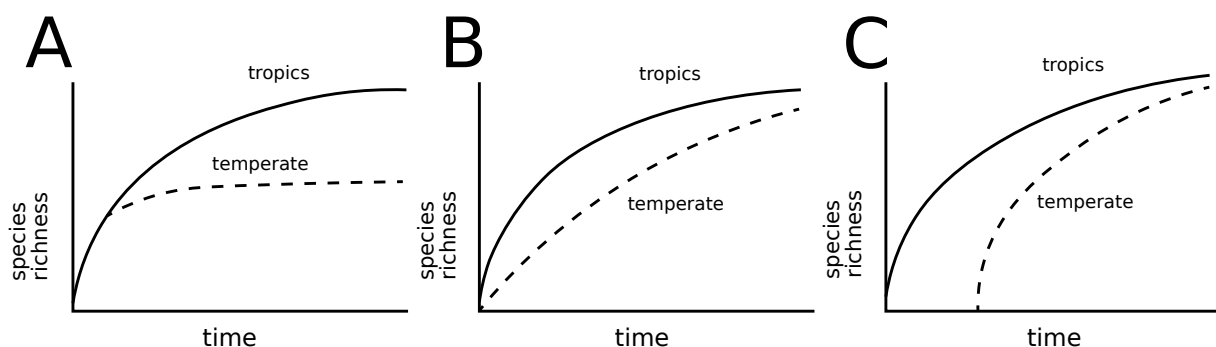


Figure 1. **A** difference in carrying capacity. **B** difference in diversification rate. **C** difference in the starting point of diversification. Note that in each graph only one factor is changed.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** The higher variance in species age in the tropics compared to temperate regions is an argument supporting the hypothesis C.
- B.** The reappearance of the diversity gradient even after the global ecosystem catastrophe would argue against the hypothesis C.
- C.** Hypothesis B is supported if greater seasonal variation would increase the diversification rate.
- D.** The fact that most temperate taxa can be found in the tropics, but not vice versa, supports the hypothesis A.

15

Walker circulation is the model that describes how temperature differences across the Pacific Ocean can explain local pressure and precipitation:

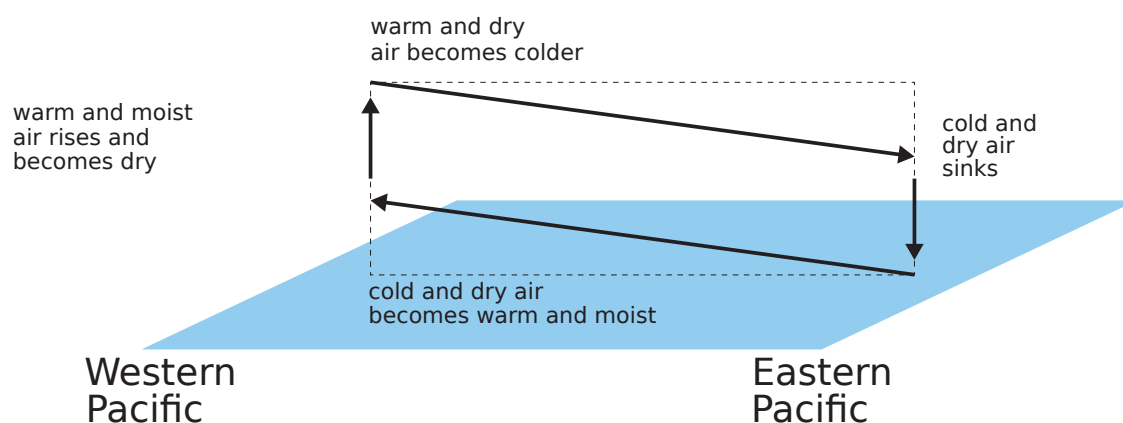


Figure 1. Walker Circulation.

Alterations in Walker Circulation are called El Niño Southern Oscillation (ENSO). This oscillation has 3 phases: Neutral (normal Walker Circulation), El Niño (weak or reversed Walker Circulation), and La Niña (strong Walker Circulation). Here are some examples of the influence of ENSO on smaller ecosystems:

Theoretical Exam - Part A



Q3-4

English (Official)

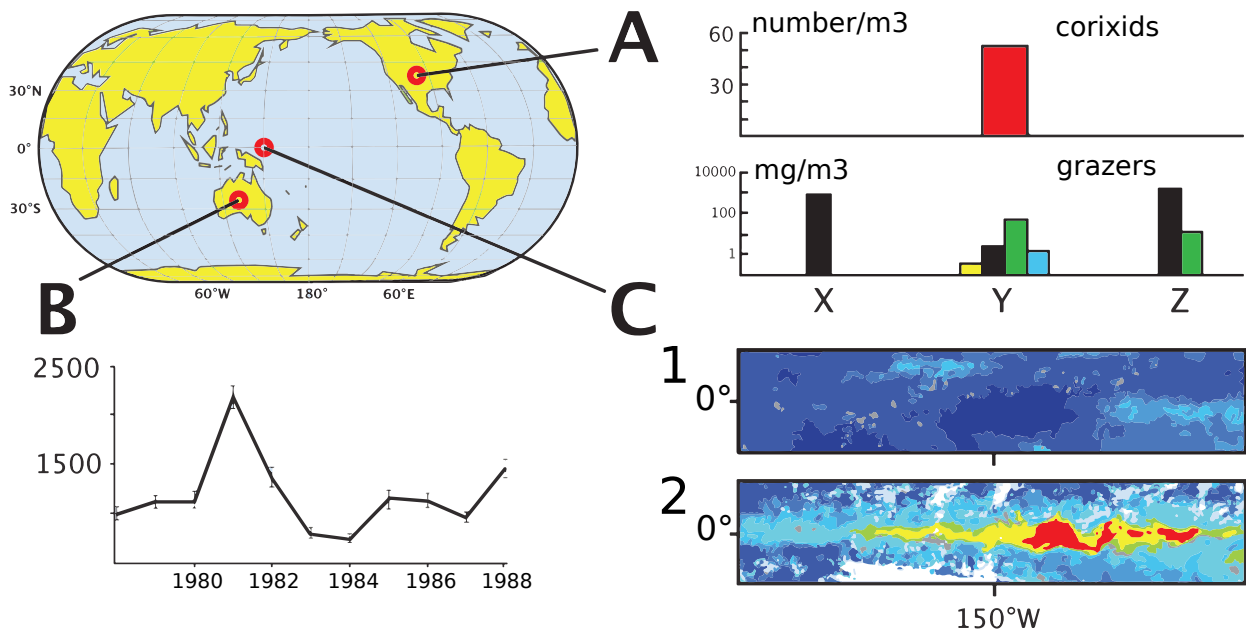


Figure 2. Top left: Global context of the smaller ecosystems mentioned. A, B, and C represent data from the corresponding ecosystems.

Location	Ecosystem/Community	Changes
A	Great Salt Lake grazers (native species represented by 4 colors) and corixids (invasive freshwater predators)	Ecosystem in years X, Y, and Z
B	Australian red kangaroo population	Size of kangaroo population (in thousands)
C	Intertropical Convergence Zone - winds blowing the surface of the water cause upwelling of deep-nutrient-rich water	Two consecutive years (C1 and C2); color represents productivity of algae ranging from low (blue) to high (red).

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. In neutral Walker Circulation, the Western Pacific has higher terrestrial ecosystem productivity than the Eastern Pacific.

B. Increase in the number of red kangaroos in 1988 was potentially caused by El Niño.

C. C1 shows pre-El Niño year and C2 is El Niño year.

D. Changes during year Y are probably caused by La Niña.

16

Fractal geometry can be illustrated by Mandelbrot's question: How long is the coast of Britain? The answer depends on the scale of measurement.

Analogously, ecosystems exhibit scale-dependent resource availability. For instance, measuring Admiralty Island's coastline from the perspective of an eagle (using the distance between nests) yields 761 km, whereas considering barnacles (requiring 2 cm of space) results in 11,000 km.

Figure 1B shows the relationship between the coastline length of Admiralty Island and the scale at which it is measured, as defined by the equation on the graph. A similar relationship exists for the amount of resources available for a species that operates at a given scale, as well as for its biomass.

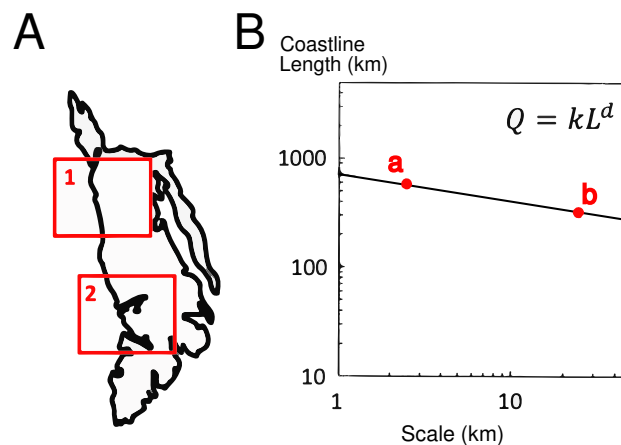


Figure 1. **A** Admiralty island. **B** Log-log graph of resolution (scale) and the length of Admiralty coastline; a, b - species; Q - resource available or biomass or coastline length, k - constant, L - scale, d - fractal dimension describing the complexity of the pattern, more complex patterns correspond to higher values of d.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** The graph for region 1 will have a steeper slope than the graph for region 2.
- B.** The number of individuals in an ecosystem consisting solely of species operating at scale **b** is larger than the number of individuals in an ecosystem consisting solely of species operating at scale **a**.
- C.** According to this theory, along with a decrease in the number of individuals at high trophic levels, all predators should have a larger body size than their prey.
- D.** Social behavior, such as the formation of herds, influences the scale of perspective.

17

Water is a common renewable resource on Earth; however, after its use, water loses some of its properties, such as purity, heat content, and potential energy. While they eventually will be restored, this happens on a geological timescale. Less than 1% of total water is available for human use – renewable freshwater resources (RFWR) – and even from this small fraction of water, only 10% is enough to fulfill the needs of humanity. While theoretically, there is more than enough water, many regions still experience a *water crisis* – a lack of accessible RFWR or an inability to utilize available RFWR.

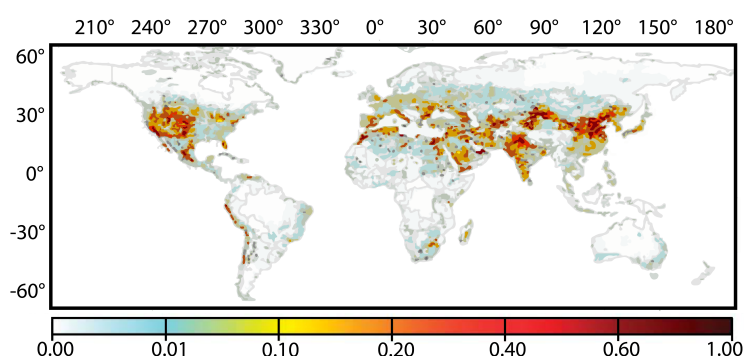


Figure 1. The world map with R_{ws} values.

$$R_{ws} = \frac{W - S}{Q} \quad (1)$$

$$A_w = \frac{Q}{C} \quad (2)$$

Equations: R_{ws} - water scarcity index, A_w - water crowding indicator, W - total annual water withdrawal by population, S - total water use from desalinated water, Q - RFWR, C - population size.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Higher human activity leads to shorter mean residence time of water molecules in reservoirs.
- B.** Low R_{ws} indicates the absence of a water crisis
- C.** Correlation between R_{ws} and $1/A_w$ is weaker in regions with poor water infrastructure.
- D.** Food import would be a better long-term solution for the water crisis in dry regions rather than water import.



Ethology

18

Roads are responsible for habitat fragmentation, impeding wildlife movement via the “Barrier effect,” which combines direct mortality from collisions with animal avoidance behaviour. Note that animal response to moving cars can resemble their reaction to natural danger stimuli. The research identified four types of animal behavioural responses (see Table 1) based on their perceived danger from traffic. Each animal species typically exhibits only one of these behavioral responses

Behavior type	Description
Speeders	Their primary response to threats is to flee across the road.
Avoiders	Avoid the road at much lower traffic volume and remain further from the road than other types
Nonresponders	Do not cease their movement at any level of traffic intensity
Pausers	Reduce their speed by freezing, which increases the time spent on the roadway

Table 1. Types of animal behavioural responses to traffic. Traffic volume entails the number of vehicles passing a point on a road segment.

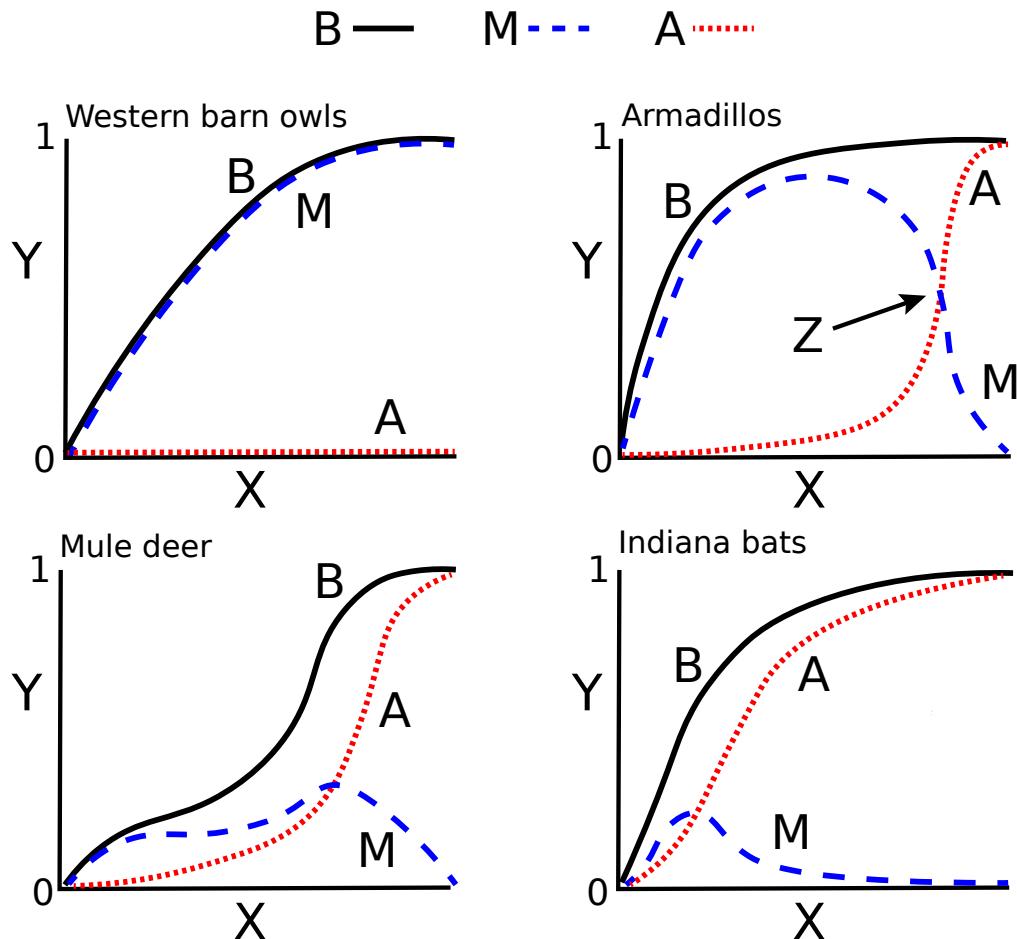


Figure 1. The total barrier effect (**B**, black solid line) from mortality (**M**, blue dashed line) and avoidance (**A**, red dotted line) for the four response categories. **X** - traffic volume in arbitrary units. **Y** - magnitude of the barrier effect in term probability (from 0 to 1).

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Nonresponding behaviour is more likely to exist in top predators of a food chain.
- B.** Relative steadiness in the mortality of mule deer after an initial increase during low traffic volume is due to the mule deer's road-avoiding behaviour.
- C.** Point Z indicates the moment when armadillos are more likely to start pausing at the road edge than the road surface
- D.** Indiana bat is probably a speeder.

19

Individual progress and subsequent social learning are important aspects of group living. The progressive accumulation of culture within a group over time is called Cumulative Cultural Evolution (CCE). The following study aimed to investigate the interplay between CCE and collective decision-making. Rock pigeons (*Columba livia*) building routes between two distant points were taken as a model system.

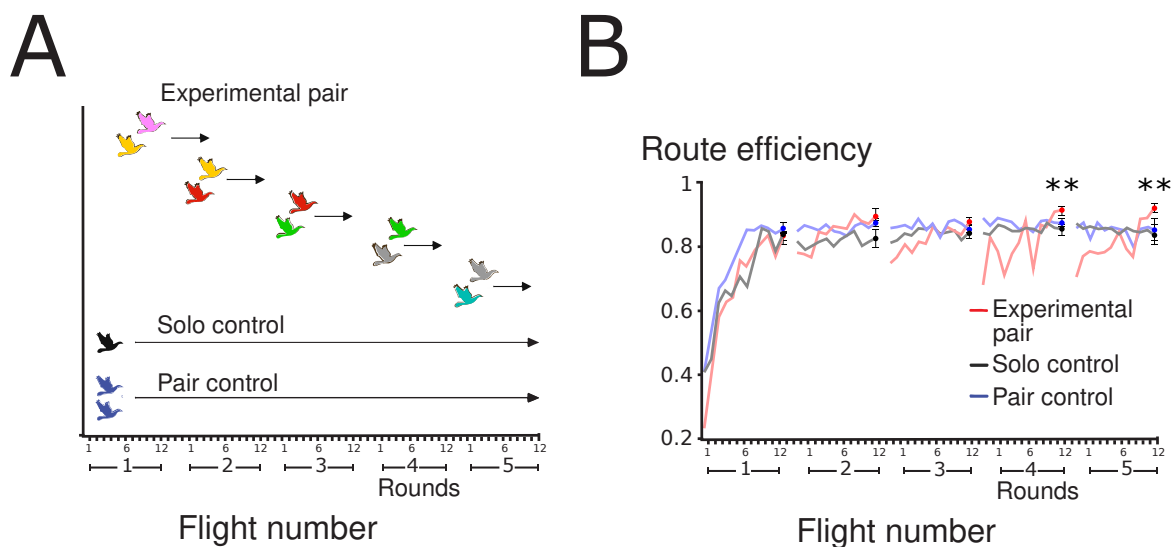


Figure 1. **A** In solo and pair controls the same birds fly all 60 times while in the experimental group, one of the birds is replaced every round (12 flights) with a new one. After **each round**, the performance on the last flights of the experimental pair and both controls were compared (** - significant difference). Route efficiency is calculated relative to the straight line connecting two points. **B** Change in route efficiency across flights, grouped by rounds.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** There is evidence of social learning in the pigeon community.
- B.** Comparing the mean performance of each group within each round may lead to incorrect interpretations of the experimental results.
- C.** In the experimental group, the new pigeon takes an active part in developing the route.
- D.** Collective decision-making is the main reason for the difference between the effectiveness of the routes of the experimental group and control groups.

Genetics and Evolution

20

Imagine a planet inhabited by animal-like creatures capable of both meiosis and mitosis, where the fundamental principles of genetics apply. This species is distinguished by two alternating heteromorphic generations: haploid and diploid.

The haploid (n) generation consists of intelligent beings who dwell in urban environments and form pairs of sexual partners. In contrast, individuals of the diploid ($2n$) generation are non-rational and aggressive and are reared in specialized nurseries. The haploid pairs entrust their offspring to these nurseries, where the diploid organisms give rise to a new haploid generation.



In one locus of these organisms, there are three alleles: $A1$ (most dominant) $> A2 > A3$ (most recessive). Among the $2n$ generation, 1% of organisms have the $A3$ phenotype, 8% have the $A2$ phenotype, and 91% have the $A1$ phenotype.

The entire population is in genetic equilibrium.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Individuals with the $A1$ phenotype make up more than 75% of the haploid generation.
- B.** There are two possible genotypes for individuals with the $A2$ phenotype in the $2n$ generation
- C.** Each haploid organism has one "grandfather" and one "grandmother", from each of which it has exactly 50% of its genetic material.
- D.** When a recessive lethal mutation that blocks mitosis occurs in this gene, it can persist in the population for many generations.

21

The 'Out of Africa' theory postulates that modern humans originated in Africa and subsequently migrated to different parts of the world. Indeed, large-scale analyses of human genomes strongly support this theory. An example of such support can be observed in the pronounced negative correlation between population genetic diversity and distance from East Africa (Figure 1). Effective population size refers to the size of an idealized population with the same genetic diversity as in the observed population as in all present genetic diversity within the observed population has been concentrated in a more limited number of individuals.

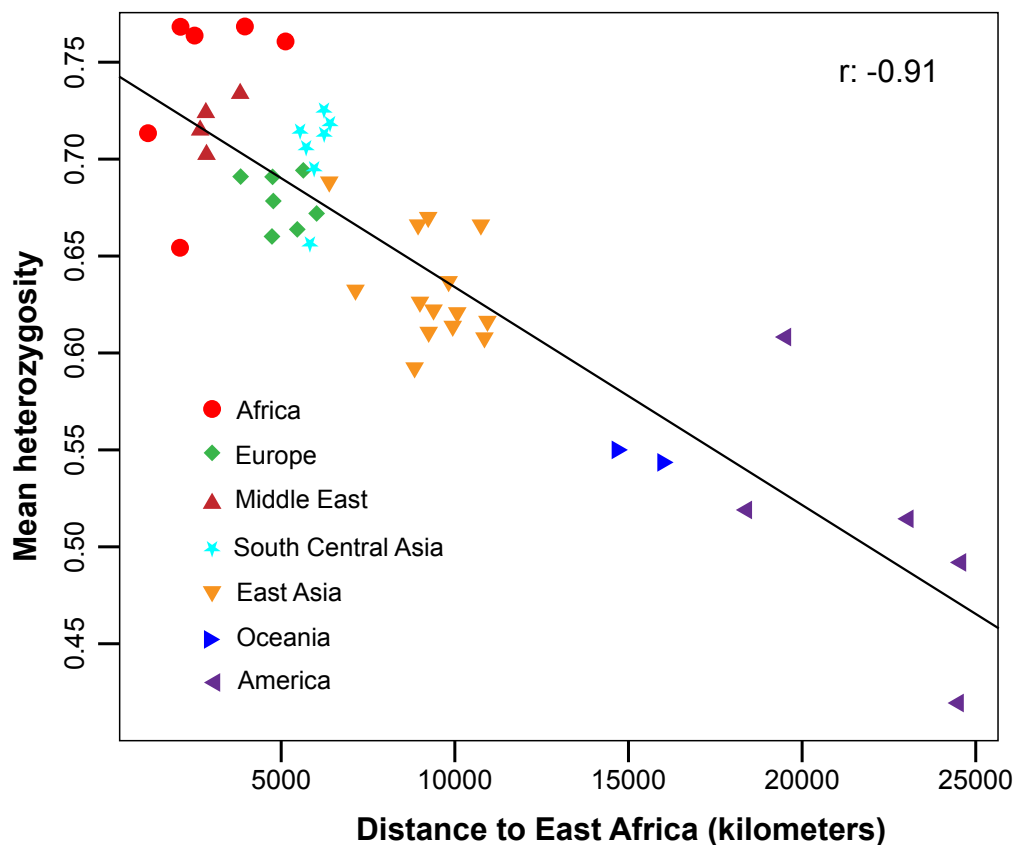


Figure 1. Average heterozygosity in humans vs distance from East Africa.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. Populations further away from East Africa have larger long-term average effective population sizes.

B. A slightly deleterious mutation is less likely to get fixed (frequency = 1) in the African population compared to the native American population

C. The reduced genetic diversity in non-African populations is likely due to the founder effect.

D. Figure 1 could represent the heterozygosity of DNA polymerase genes.

22

During the first step of ethanol metabolism in humans, alcohol dehydrogenase (ADH) converts ethanol to toxic acetaldehyde that can accumulate in the body.

ADH1B gene of alcohol dehydrogenase has 2 alleles with varying levels of enzyme activity: ADH1B*2 is associated with rapid alcohol metabolism compared to ADH1B*1. The ADH1B*2 distribution has a distinct geographical pattern (see Fig.1B).

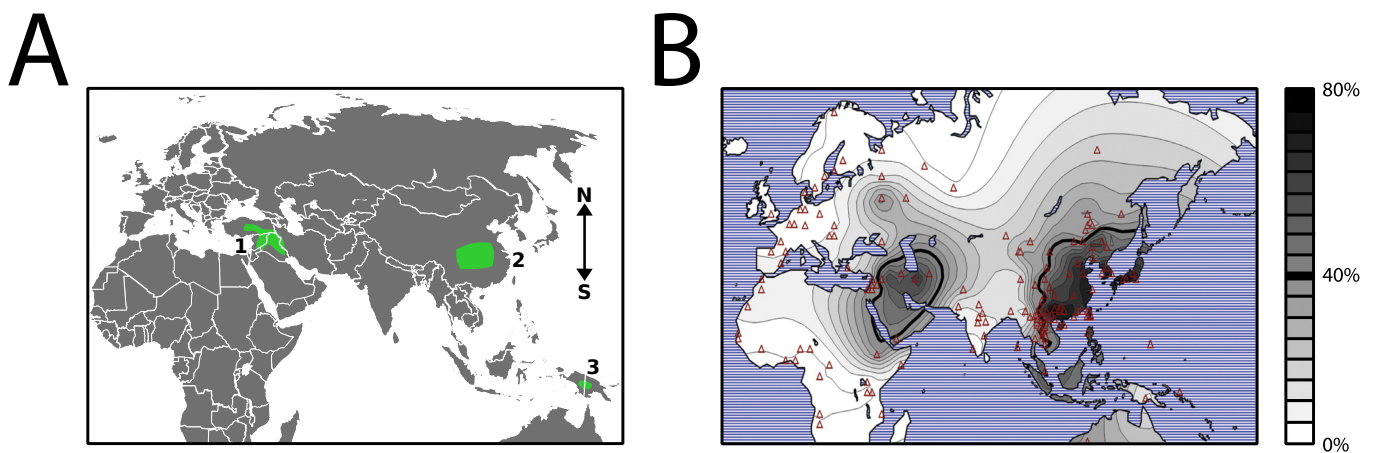


Figure 1. **A** The historical origins (Areas 1-3) of agriculture emerged 10,000 years BP ("before present"). **B** Global contour plot of the ADH1B*2 allele frequency. The red triangles on the map are points of the data collection.

On your answer sheet, indicate "T" for true statements and "F" for false ones 1.0pt

- A.** The ancestral allele of the ADH1B gene evolved to degrade high amounts of exogenous alcohol.
- B.** ADH1B*2 is likely protective against sustained ethanol abuse.
- C.** Agriculture in Area 3 has been strongly associated with ethanol production.
- D.** Based on the given data, it is more plausible that positive selection on the ADH1B locus occurred independently in Areas 1 and 2 than negative selection occurred elsewhere.

Theoretical Exam - Part A



Q5-5

English (Official)

23

Aizhan studies polymorphism of locus JR_189021 in *Drosophila melanogaster* that has only two alleles – A1 and A2. To study the fitness of genotypes, she runs a long-term evolution experiment with ten independent populations of 1,000 flies for 150 generations and measures the frequency of allele A1 in each generation (Figure 1). After completing it, she decided to change the population size and run an experiment using the same setup (Experiment #2). Additionally, she estimated the expected theoretical fit using the fitness values of each genotype reported in the literature. The locus is not under frequency-dependent selection. Assume that homozygous phenotypes are at the extreme of phenotypic distribution. Allele and genotype frequencies within a given generation can be assumed to follow Hardy-Weinberg equilibrium.

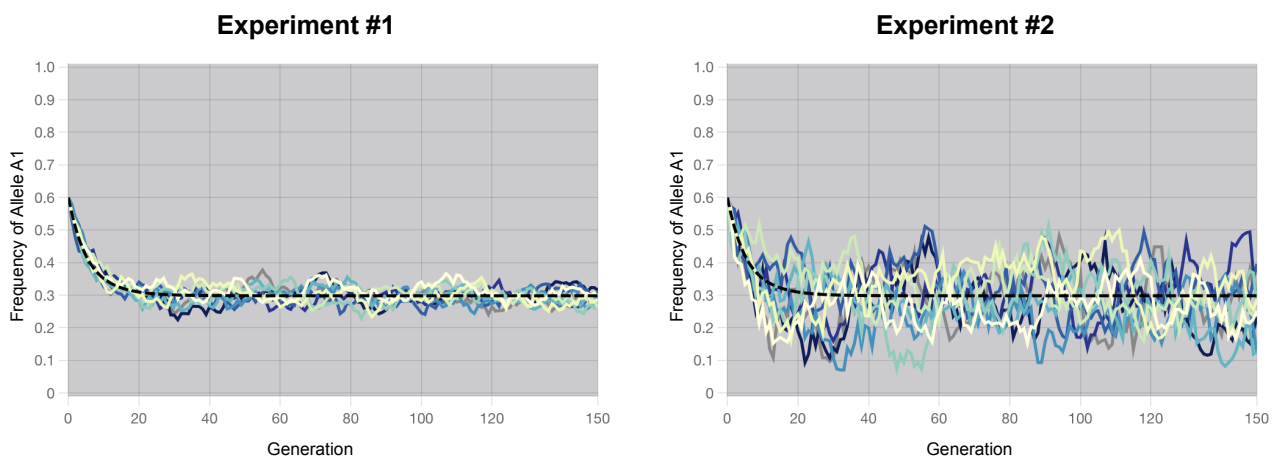


Figure 1. The frequency of allele A1 across 150 generations in experiments #1 and #2. Each curve represents a different replicate, while the dashed line is the theoretical fit of all ten populations.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** In the long term, the locus is under the directional selection.
- B.** For experiment #2, Aizhan increased the population size.
- C.** Flies with the A1A2 genotype have the highest fitness.
- D.** Flies with the A1A1 genotype have higher fitness than flies with the A2A2 genotype.



24

While central dogma claims that synonymous substitutions (which do not change the primary sequence of the polypeptide) do not have any effect on protein sequence and its cellular function, codons are not used to the same extent in the vast majority of sequenced genomes. This is known as the codon usage bias. For example, among four codons that encode glycine in *Escherichia coli*, GGU and GGC have higher abundance than GGA and GGG codons. The primary driver for such unequal codon usage is to match the available pool of tRNA molecules.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Protein coding genes that are involved in ribosomal assembly have very high codon usage bias.
- B.** Transgenic material that was not corrected for codon usage bias of the recipient's genome will have lower translational efficiency relative to the corrected one.
- C.** Codon usage bias is not found in viruses.
- D.** Methionine will have one of the strongest codon usage biases because it is always the first amino acid in the protein.

25

Mitochondrial RNase P is an endonuclease composed of three subunits (Figure 1B). Mutations in this enzyme are often associated with the development of combined oxidative phosphorylation deficiency syndrome (COXPD54) in humans. The figures below show various information regarding RNase P and its mutations.

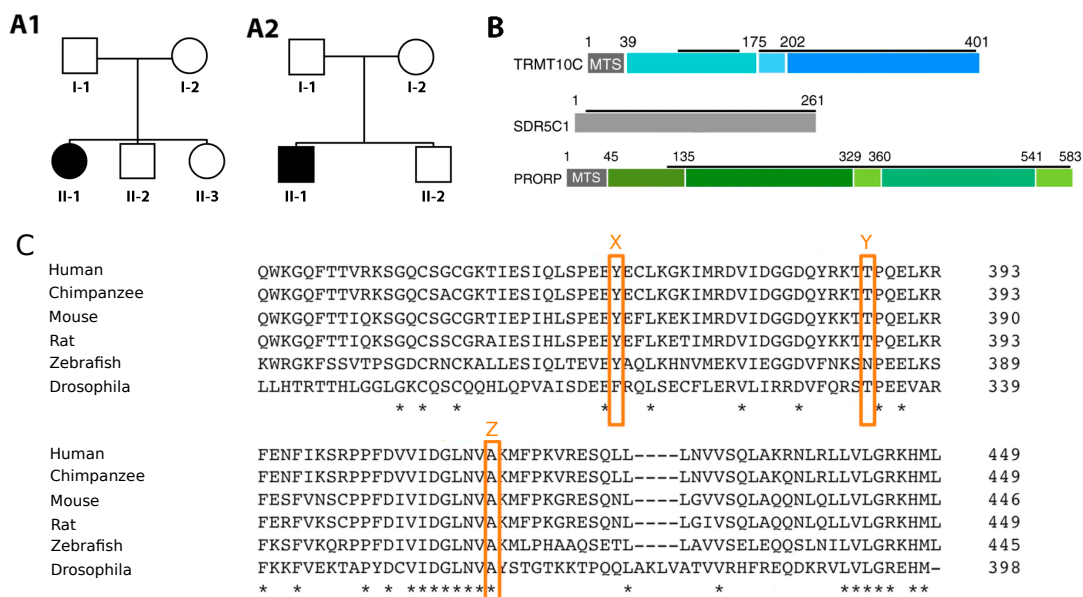


Figure 1. **A1 & A2** are pedigrees of two families showing distinct missense mutations resulting in the COXPD54 syndrome in shaded individuals; mutation X for A1 and mutation Y for A2. **B** RNase P subunits; (MTS - mitochondrial targeting sequence). **C** Alignment results of the RNase peptide segment across various organisms. Positions affected by the mutations are highlighted in orange boxes. The mutations leading to COXPD54 syndrome are Tyr (Y) → His (H) in position X; Thr (T) → Ala (A) in position Y; Ala (A) → Val (V) in position Z.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. Within the primary structure, it can be assumed that the mutation at position X is located closer to the active site of the enzyme than the mutation at position Z.

B. Mutation at position Y involves transversion (purine to pyrimidine change).

C. All of the RNase P subunits assemble within the cytoplasm before being transported into the mitochondrion.

D. Knowing that individual II-3 (A1) is the carrier of mutation at position X, the probability of the couple II-3 (A1) and II-2 (A2) having a child with the syndrome is 1/6. (Assume Mendelian inheritance.)

26

Mass extinctions occur when environmental changes outpace rates of species adaptation. One way to quantify this change is by measuring the addition of inorganic carbon to oceans over time. Significant changes in the flux between inorganic and organic carbon reservoirs are termed carbon cycle perturbation events. **Mass change** measures the magnitude of change in inorganic carbon mass in oceans. Another quantifying metric of a carbon cycle, **isotopic shift** measures the change in carbon isotopic composition during the event.

In the last 220 million years, the biological pump, which transports organic carbon and calcium carbonate from the ocean's surface to the deep sea, has significantly strengthened.

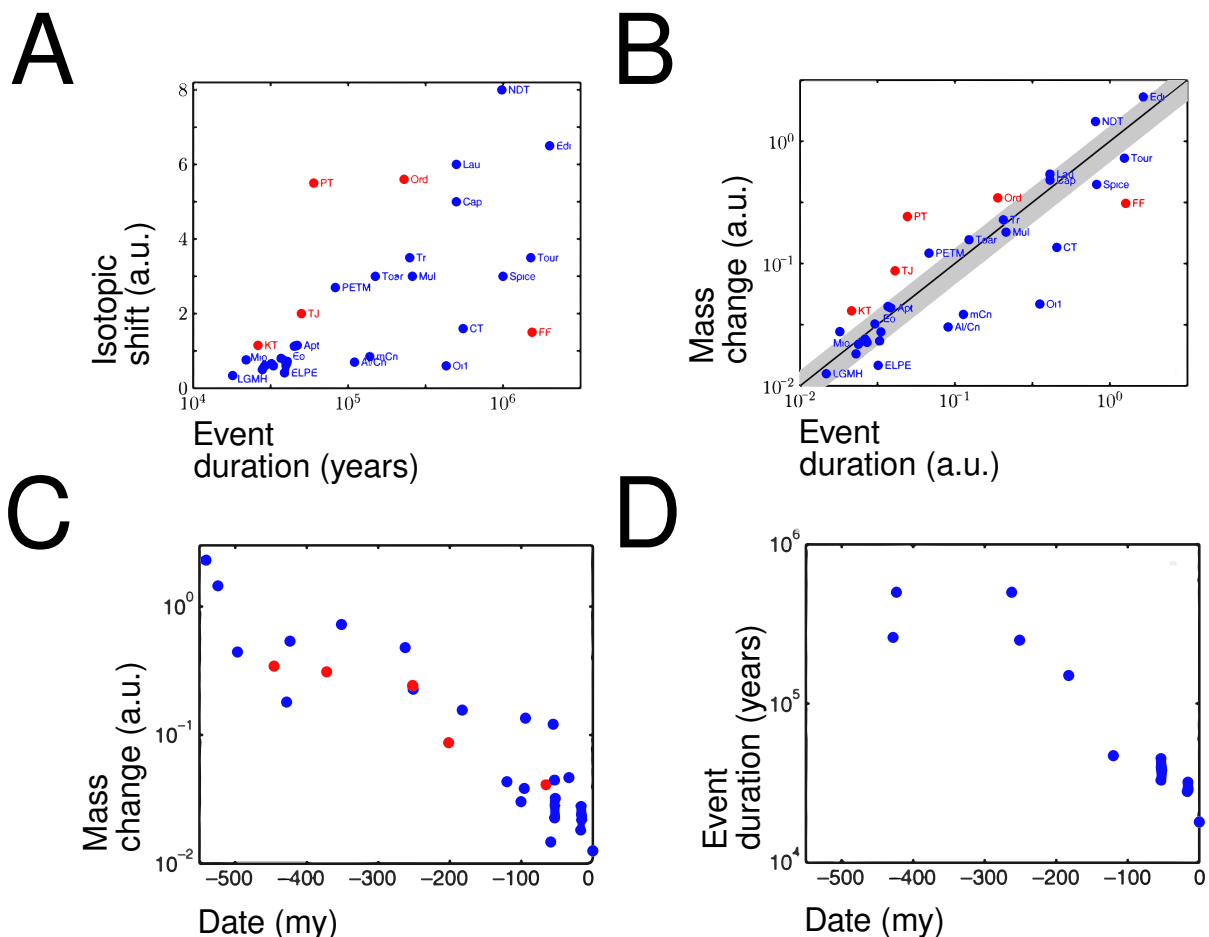


Figure 1. Carbon-shifting processes plots.

A Isotopic shift vs Event duration. **B** Mass change vs Event duration. Gray shaded area around the line represents error margin of the fit line. **C** Mass change vs Date. **D** Event duration vs Date; my - million years, a.u. - arbitrary units; Red dots: events considered as mass extinctions. Blue dots: other carbon perturbation events. Units may differ between graphs. Note that mass extinction events are not included in graph D.



On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** One of the mass extinction events is likely caused by mechanisms distinct from those seen in other events.
- B.** The lack of information about minor events that happened early in Earth's history alone can explain the trend in Graph C.
- C.** The line in Graph B represents a critical threshold, above which a carbon perturbation event is likely to be associated with extinction catastrophe.
- D.** A more efficient biological pump results in smaller and shorter carbon perturbation events.

27

Five mutations in beta-lactamase can significantly affect its ability to degrade third-generation antibiotics like cefotaxime: Mut1, Mut2, Mut3, Mut4, Mut5. Since they can appear in any order there are 5! (=120) potential trajectories of resistance development. However, only 18 of them are evolutionarily accessible. The term "evolutionarily accessible" refers to the ability of a particular mutational pathway to produce an advantageous phenotype during the evolution. Implications from this simple model could be used to understand the evolution of more complex traits.

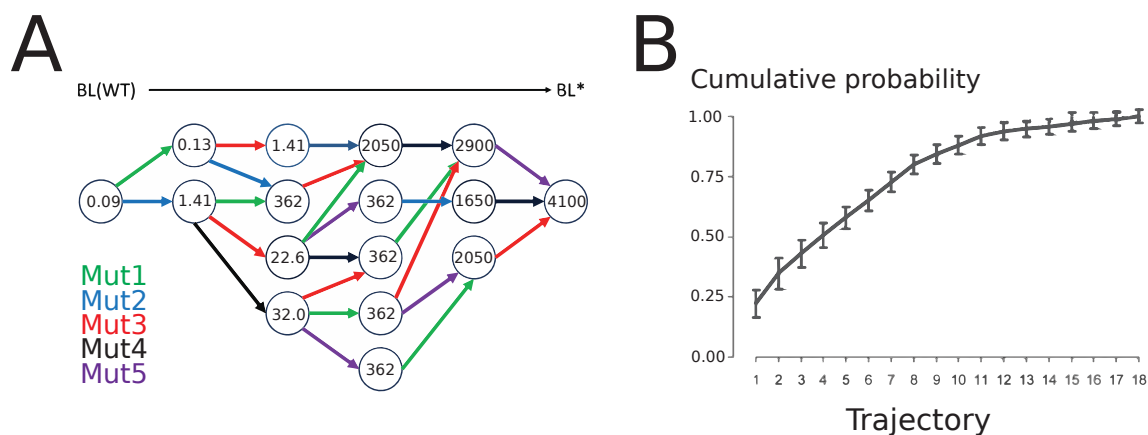


Figure 1. **A** Graph showing the ten most probable trajectories leading from wild-type beta-lactamase (BL(WT)) to an improved version (BL*), the efficiency of each phenotype indicated on the node. Colored arrows represent the five potential mutations. **B** The cumulative probability of each of the 18 possible trajectories.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Some mutations require additional mutations to have a significant effect.
- B.** The trajectories 1-18 (Figure 1B) are arranged based on the increasing probability of occurrence.
- C.** A mutation's effect on fitness influences the probability of this specific mutation occurring.
- D.** The final fitness of the trajectory is the primary factor affecting the evolutionary accessibility of the trajectory.

28

Mutations have different effects ranging from strongly deleterious to highly adaptive. The frequency, with which a particular mutation appears de novo, is described by the fundamental property of each species - distribution of fitness effects (DFE). There are two direct methods of finding DFE: induce mutations and check the fitness of each mutation or prepare mutation accumulation lines and compare their fitness distribution with the initial line. DFE can also be inferred indirectly from sequencing data that compares rates of non-synonymous (N) and synonymous (S) substitutions using the dN/dS ratio between different species.

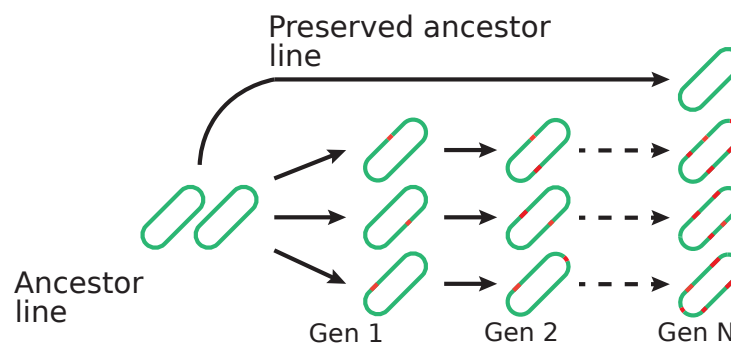


Figure 1. Scheme of mutation accumulation line experiment.

$$N_e \times s < 1 \quad (1)$$

(1) mutations with s satisfying this inequality are called effectively neutral. N_e - effective population size; s - absolute value of strength of selection.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Individual effectively neutral mutations are fixed only due to genetic drift.
- B.** Species with large N_e have higher adaptability.
- C.** The mutation accumulation line method always underestimates the frequency of deleterious mutations.
- D.** dN/dS is proportional to the ratio of deleterious mutations.

29

Retroviruses are RNA viruses that have RNA to DNA reverse transcription steps in their life cycle. Some can become endogenous retroviruses (ERVs), where they integrate into the host genome and become heritable. Retrotransposons are genetic elements that can spread over the genome using RNA intermediate for translocation. There is some evolutionary relationship between retrotransposons and ERVs. ERVs and retrotransposons are valuable parts of our genome that provide extra genetic material for evolution.

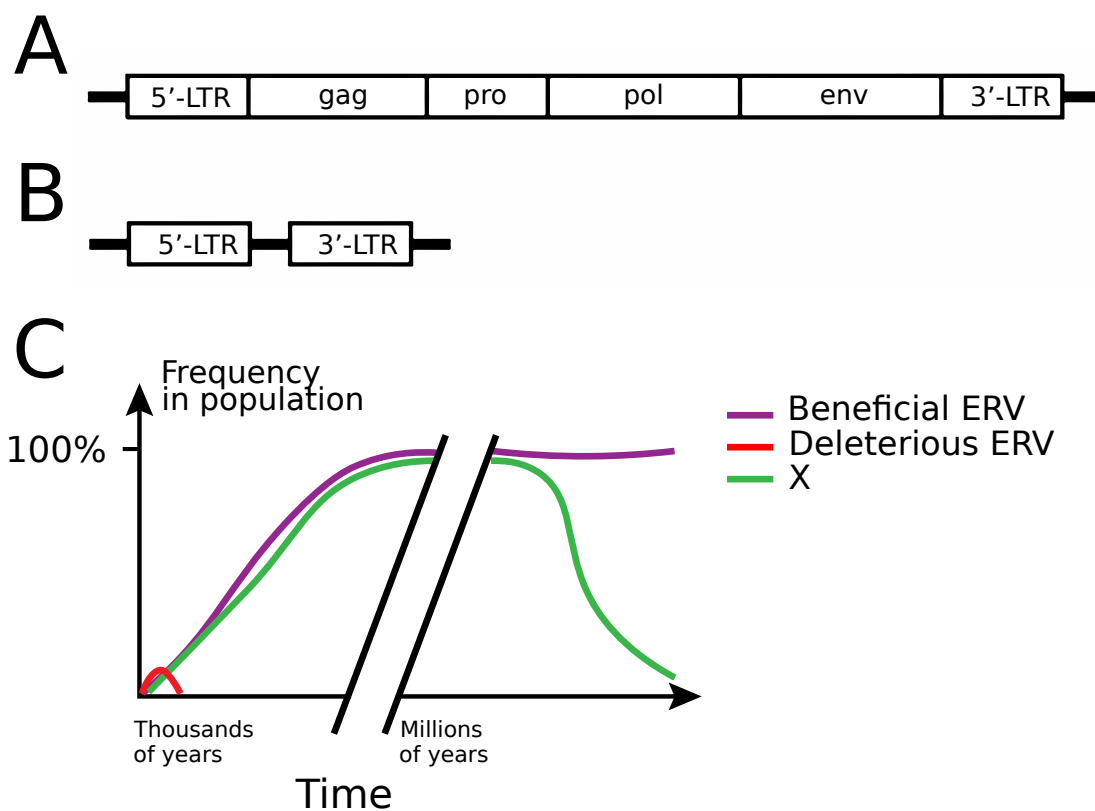


Figure 1. **A** Common structure of ERV, LTR - identical long terminal repeats, gag - virion structural protein, pro - viral protease necessary for virion maturation, pol - reverse transcriptase, env - glycoprotein envelope protein. **B** Solo-LTR (empty ERV derivative). **C** Changes in frequencies of beneficial and deleterious ERVs after many generations.



On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Whether or not the provirus will become an ERV depends on the type of cells infected by the retrovirus.
- B.** ERV should lose at least two genes to no longer be a virus.
- C.** Solo-LTRs are the least common type of ERV derivatives found in the genome.
- D.** If an ERV encodes a restriction factor preventing entry of a species-specific exogenous retrovirus, it can have an evolutionary history depicted by line X.

Plant Anatomy and Physiology

30

Gibberellin, an essential phytohormone responsible for cell wall suberization, undergoes complex transport within plants involving a variety of transporters. Below are figures depicting results from studies on different membrane transporters of gibberellin.

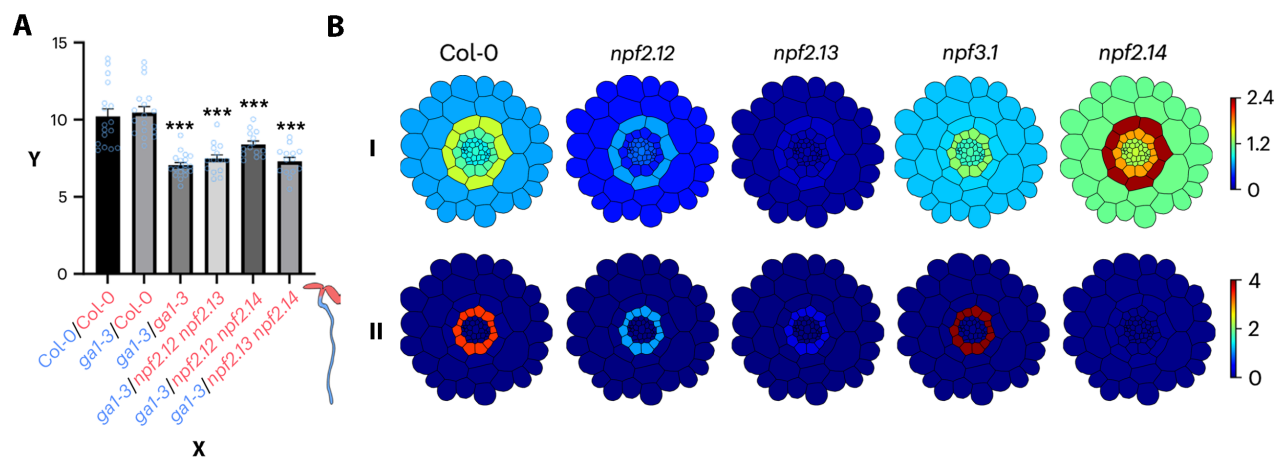


Figure 1. **A** Fluorescence intensity (Y) of root endodermal cells in grafted plants (X, root/shoot). Samples were treated with a fluorescent marker for suberin (Nile red); asterisks indicate a significant difference from the wild type. Col-0 - wild type, ga1-3 - mutant lacking gibberellin synthesis, npf__ - mutants lacking expression of a specific type of transporter(s). **B** Cytoplasmic (I) and vacuolar (II) concentrations of gibberellin (arbitrary units) in the root.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A. Transport of gibberellins occurs in the following direction: root → shoot.
- B. Vacuoles of the pericycle cells are involved in the regulation of threshold values of gibberellin concentration.
- C. The npf3.1 mutant is vulnerable to water and mineral imbalances, as well as toxins, compared to wild type.
- D. All the transporters listed are located on the plasma membrane.

31

During the Calvin Cycle, carbon dioxide is fixed by RuBisCo, an enzyme in plants. However, RuBisCo can also catalyze reactions with oxygen, which disrupts the photosynthesis.

Photorespiration is a process of recovering ribulose-1,5-bisphosphate (RuBP, the RuBisCo substrate) from products of RuBisCo oxygenation. Recent studies suggest it plays a significant role in NADH generation, managing the metabolic toxin 2-phosphoglycolate (2-PG), and connecting photosynthesis to nutrient assimilation and abiotic stress response pathways.

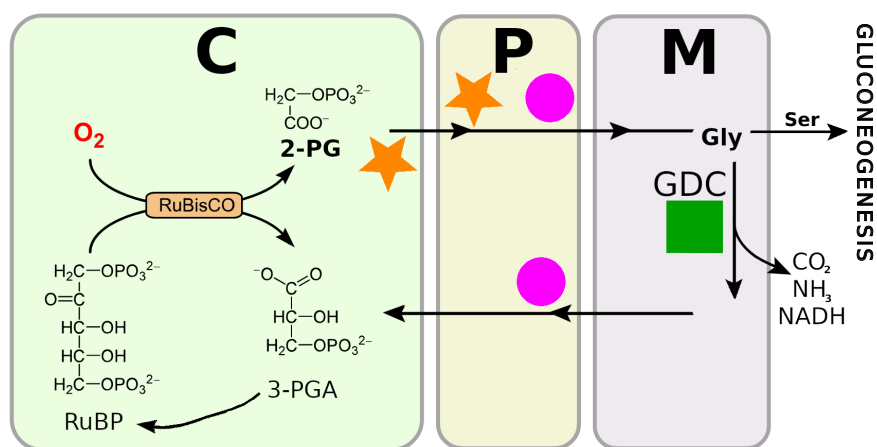


Figure 1. A schematic of photorespiration. When overexpressed, the enzyme in dark green (square) increases the rate of reactions, the enzyme in orange (stars) does not affect it, and the enzyme in magenta (circle) slows it down. GDC = Glycine decarboxylase. C = chloroplast, P = peroxisome, M = mitochondrion.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** If GDC was inhibited, the cell could still recover the RuBP lost to photorespiration through gluconeogenesis.
- B.** Rising atmospheric carbon dioxide alone should increase need for photorespiration.
- C.** If all shown peroxisome enzymes were overexpressed, photorespiration would take less time per cycle compared to the wild type.
- D.** C4 plants rely less on photorespiration than C3 plants.

32

Poaceae (grass family) stomata have a "dumbbell" shape and a stronger connection between guard and subsidiary cells. Due to this adaptation, they respond to stimuli faster than non-Poaceae stomata. Specifically, alternating hyperpolarization (**H**) and depolarization (**D**) of cell membranes allow well-synced osmotic flow by activating the ion channels, as shown in Figure 1. Non-Poaceae stomata do not sync this closely.

Due to the advanced geometry of Poaceae stomata, subsidiary cells actually lose turgor when guard cells gain it, and vice versa. That leads to the widest possible open pore, as the subsidiary cell "bends inward" to accommodate the growing guard cell.

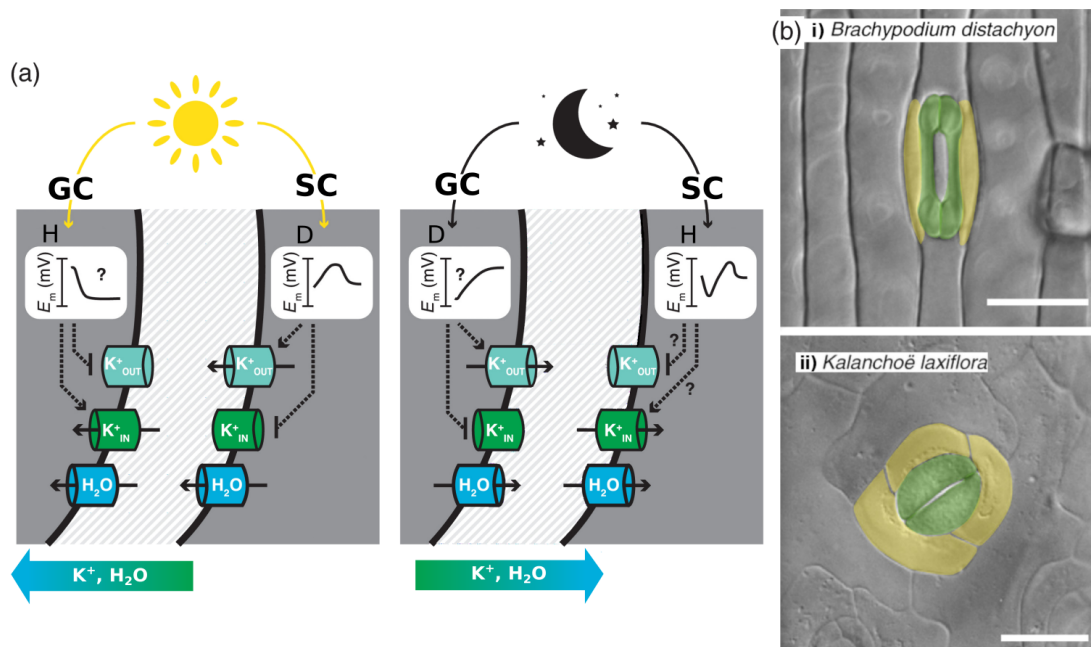


Figure 1. **A)** Schematic representation of Poaceae stomata synchronization mechanism. Guard cells are GC, and subsidiary cells are SC on the diagram. Question marks imply the effect has only partially been verified; blue H_2O cylinders are aquaporins. **B)** Highlighted micrograph of a Poaceae (i) and non-Poaceae (ii) stomata.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A. An electric pulse from an electrode connected to the stomata is able to both open and close it.
- B. Poaceae stomata would react to environmental stimuli quicker if subsidiary cells' cell walls are reinforced with lignin.
- C. Continuously potassium-deficient plants would have a larger maximum open stomatal pore area.
- D. Increased expression of aquaporins would only affect the rate of opening/closing.

33

Xanthophylls are yellow-orange colored and fat-soluble photoprotective pigments. This is likely an adaptation to the unforgiving sunlight in dry ecosystems. As excess light leads to the accumulation of protons in the thylakoid's lumen, this lower pH triggers a transformation of precursors (Pre-Z) into zeaxanthin (Z). All of them are xanthophylls.

When protonated, Z changes the conformation of photosystem II to dissipate extra light energy as heat. Reduced ascorbate is a cofactor for de-epoxidase, the enzyme that catalyzes the Pre-Z → Z reactions.

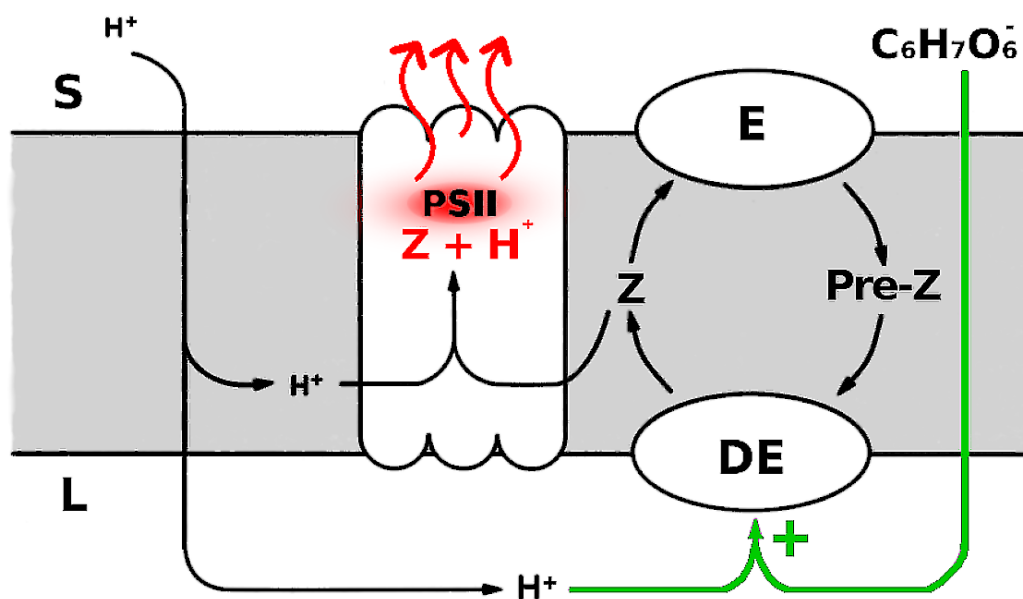


Figure 1. A diagram of the thylakoid membrane, where S – stroma, L – lumen, E – epoxidase, DE – de-epoxidase, PSII – photosystem II, $C_6H_7O_6^-$ – ascorbate, red wavy arrows – heat, and green arrows with the plus sign – activation.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. Sun-tolerant plants with the deleted de-epoxidase gene will exhibit shade preference instead.

B. A temperate steppe shrub population will have higher xanthophyll leaf content as compared to a forest understory shrub of the same species.

C. The hot and sunny subtropical climate would lead to higher total xanthophyll concentrations in thylakoids compared to a colder sunny climate.

D. If you have Vitamin C/ascorbate deficiency, you should eat leaves from the top of the canopy rather than the bottom.

34

After producing C3 sugars in the Calvin Cycle, plant cells can further produce other carbohydrates for structural growth, starch, and soluble carbohydrates. Discounting their structural use, the allocation of sugars between starch and soluble carbohydrates within the leaf can be used to assess the yield potential of crop plants.

Researchers looked into the change in the ratio of starch to soluble sugars between different growing stages across three different breeds of maize (*Zea mays*). They look into the leaf carbohydrates during two vegetative and one reproductive stages. During the latter, the fast-growing kernels require large amounts of carbohydrates, making them suitable for future human consumption.

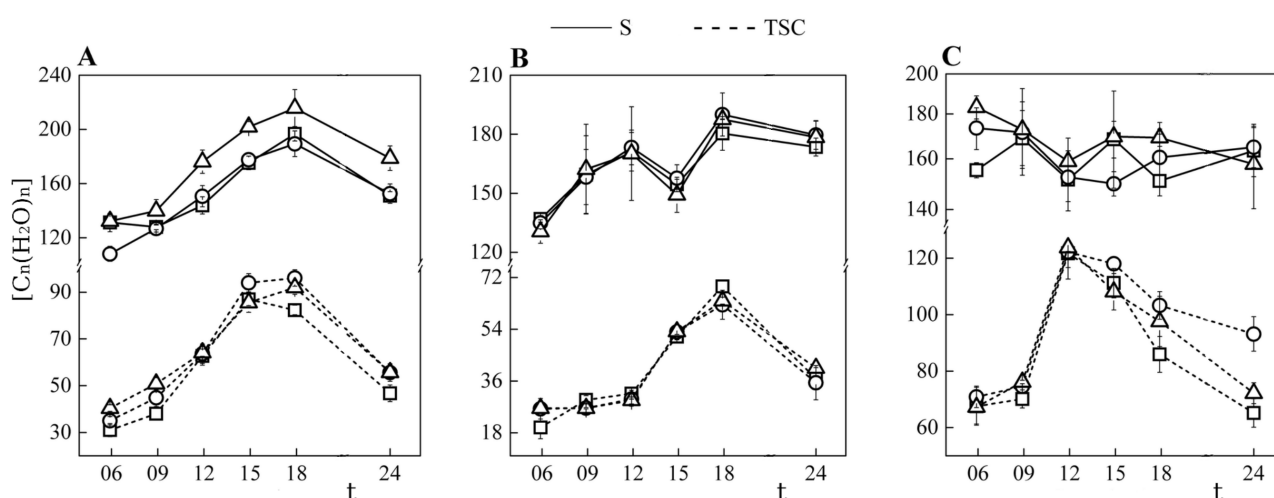


Figure 1. S – starch concentration in leaves, TSC – total soluble carbohydrate concentration in leaves. t – hour of the day. A, B, and C are plots for two vegetative stages and the reproductive stage respectively. Different shapes represent the three cultivars.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Photosynthesis begins only after 9 am based on the given graphs.
- B.** Higher peak TSC levels during the reproductive stage compared to vegetative stages can be explained by kernel growth.
- C.** The difference between TSC concentrations at 6h and 24h partially comes from cellular respiration.
- D.** In the context of selecting for bigger seeds, lower leaf starch content is a detrimental trait.

35

Fluid dynamics put an upper limit on how high a tree's water column might exist, and above that limit, water transport in the xylem will be disrupted. However, trees similar to Californian redwoods routinely grow above this limit. Scientists studied Californian *Sequoia sempervirens* from the alluvial flood plain and *Sequoiadendron giganteum* from the mountain slopes with most likely dry soil. Xylem adaptations have higher water and carbon cost upfront than stomatal adaptations, but allow plants to transpire more.

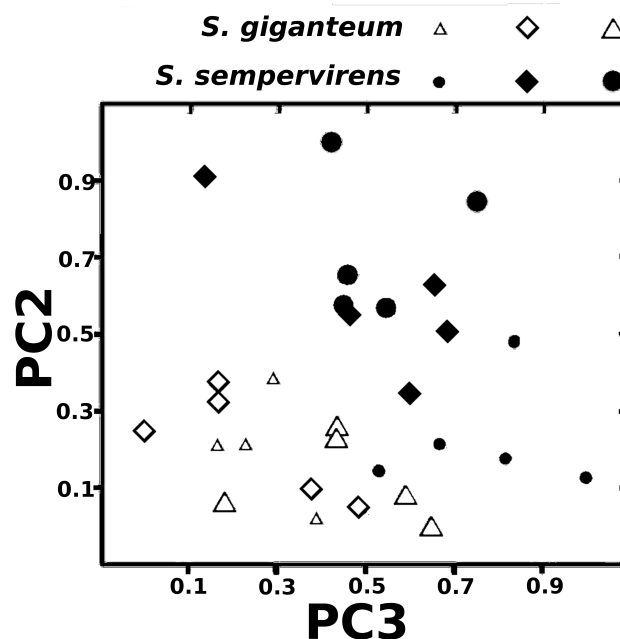


Figure 1. Plots like the one above condense many variables like leaf conductance and wood density into two categories. Low PC2 values correspond to more efficient stomatal water use, and high PC2 to more efficient xylem water use. PC3 values are inversely proportional to leaf mass and wood density. The bigger the symbol, the taller is that particular tree. Middle-size symbols are a different shape to make telling apart easier.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A. *S. giganteum* wood is on average denser than *S. sempervirens* wood.
- B. Short *S. sempervirens* trees are more adapted to resist xylem blockage.
- C. *S. giganteum* might have higher PC2 scores if it is irrigated for several generations.
- D. *S. sempervirens* wood density has a strong negative correlation with height.

36

Aquatic carbon primarily exists in the dissolved form, and due to the formation of H_2CO_3 (carbonic acid), there are three main species – H_2CO_3 , HCO_3^- , and CO_3^{2-} . Despite that, Rubisco only uses CO_2 as the carbon source.

The oceanic pH is around 8, and freshwater pH is around 7. Generally for aquatic plants, epidermal cells take up carbon directly, but diffusion is significantly slower in water than in air. Plants can uptake HCO_3^- faster than CO_2 . Some plants use intracellular carbonic anhydrase as a quicker carbon sourcing mechanism.

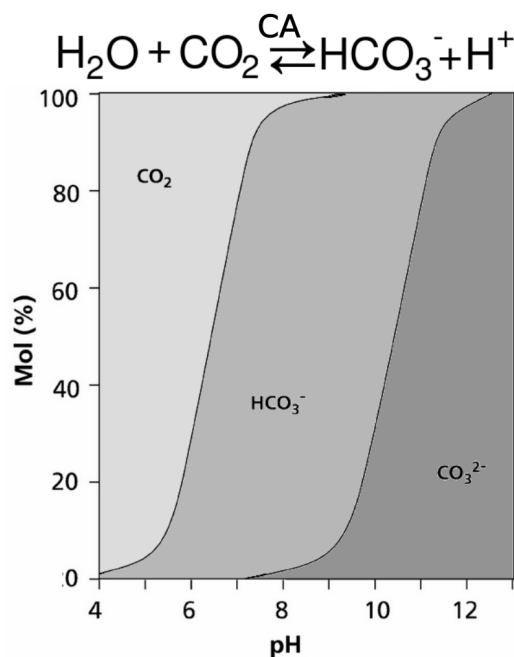


Figure 1. Reaction for which carbonic anhydrase (CA) is the catalyst. Percent concentration (Mol(%)) of three types of dissolved carbon against water pH. The two lines are the boundaries separating three types.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Fully submerged aquatic plants are likely to have thicker cuticle.
- B.** Aquatic plants have adapted to the oceanic pH range by using HCO_3^- as a CO_2 source.
- C.** In stationary freshwater, releasing protons from the epidermis might aid CO_2 intake.
- D.** Plants that use carbonic anhydrase have Rubisco with higher CO_2 fixation efficiency than plants that directly use CO_2 .

37

Figure 1 provides a schematic representation of one eudicot plant's growing root. It illustrates, through red arrows, the pathway of water solution movement within a healthy plant under optimal conditions.

Assume that the water solution inside the cells of the B zone has an osmolarity of 0.3 osmoles per liter (Osm/L).

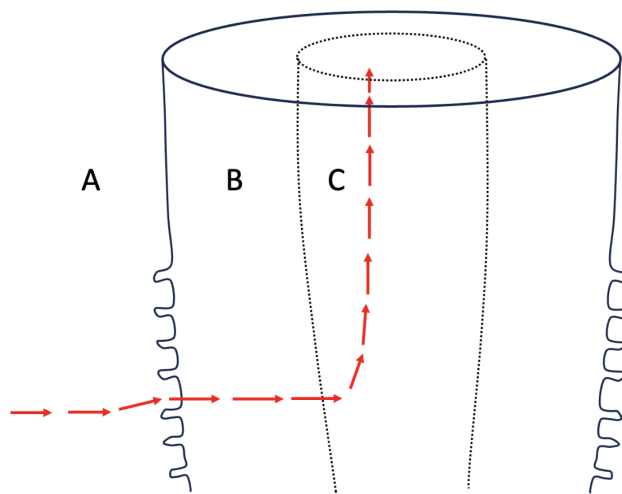


Figure 1. Diagram of a plant root; **Zone A** - soil, **Zones B** and **C** - parts of the root.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** All molecules of water cross through the plasma membrane to enter zone B from zone A.
- B.** In a healthy plant and under natural conditions, the concentration of free water molecules in zone B is greater than in zone A.
- C.** During a flood, certain plants experience cellular death in zone B. This process results in the formation of voids.
- D.** If we clean the roots of this plant and place them in a 0.2 molar NaCl solution, the cells in zone B will begin to lose water.

Animal Anatomy and Physiology

38

An electrocardiogram (ECG) records the heart's electrical activity using electrodes on the skin. Leads I, II, and III form Einthoven's triangle and provide key views of the heart's electrical axis by measuring voltage differences between the limbs. Lead I measures between the right and left arms, Lead II between the right arm and left leg, and Lead III between the left arm and left leg. In modern diagnostic medicine, 12 leads are used for a more comprehensive analysis of the heart's activity.

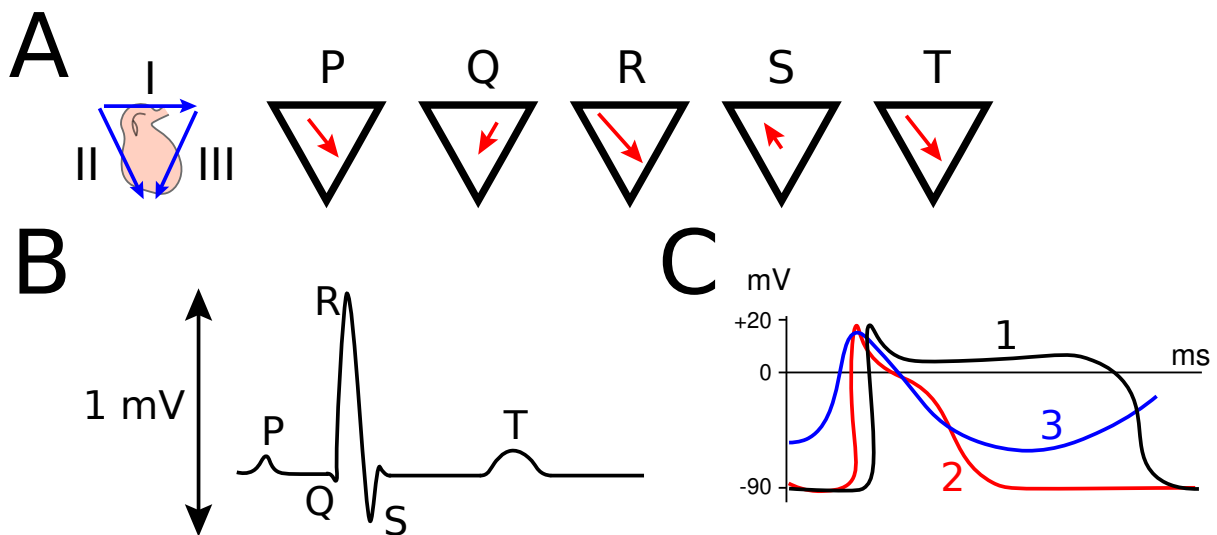


Figure 1. **A** Leads I, II, and III form Einthoven's triangle with red vectors showing the heart's mean current direction and amplitude. **B** ECG measurements along lead II with P wave, QRS complex, and T wave. **C** Membrane potential of cardiomyocytes from different heart regions during the cardiac cycle.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Graph 2 in Figure 1C was registered in a cardiomyocyte from the sinoatrial node.
- B.** Full atrioventricular node blockade would result in only the P wave being visible.
- C.** The S wave represents repolarization.
- D.** The amplitude of the P wave in Figure 1A is larger in the lead II than in the lead III.

39

Snow leopards (*Panthera uncia*) inhabit high-altitude areas in East and South Kazakhstan and are known to hyperventilate. To examine possible differences in the oxygenation properties of big cats' hemoglobins (Hbs), O_2 -equilibrium curves were measured for purified HbA and HbB isoforms of African lion and snow leopard hemoglobin under standardized conditions of pH and anion concentrations. Furthermore, the effects of KCl and DPG were also analyzed. KCl and DPG (2,3-diphosphoglycerate) are allosteric cofactors of hemoglobin.

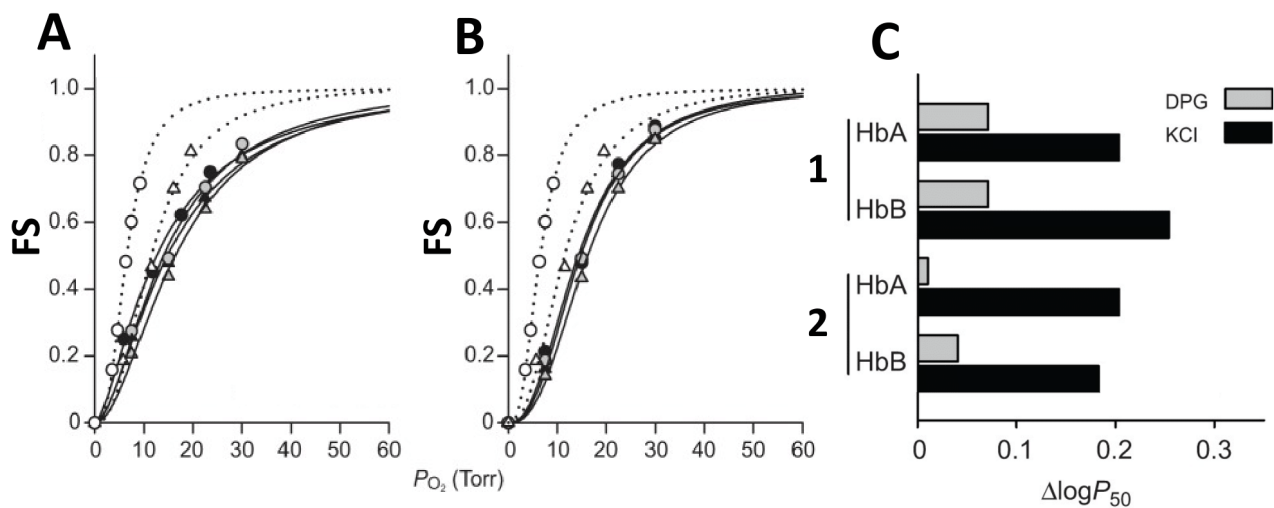


Figure 1. Hb- O_2 equilibrium curves of African lion (A) and snow leopard (B) compared with those of human adult Hb. Triangles – DPG-added, circles – DPG-free; Black-filled shapes – HbA, gray-filled shapes – HbB, white-filled shapes – human adult Hb, FS - fractional saturation (ratio of Hb- O_2 to total Hb). C shows the changes in P_{50} values from DPG-free Hb with the addition of KCl or DPG (P_{50} is the oxygen partial pressure when hemoglobin is 50% saturated with oxygen). 1 – African Lion and 2 – Snow Leopard.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. DPG has a stronger allosteric effect on hemoglobin in snow leopards than in humans.

B. Renal compensation stimulates snow leopards inhabiting high-altitude areas to excrete more bicarbonate (HCO_3^-) than those inhabiting lowland areas.

C. The hemoglobin of snow leopards is specifically adapted to low oxygen partial pressure.

D. KCl causes a stronger increase in affinity to oxygen in African lion's HbA than in snow leopard's HbB.

40

In a study examining the behavioral activity of mice and its dependence on feeding time, mice were kept on a 12-hour light/12-hour dark cycle. They were divided into two groups: one that was fed only during the light phase, and the other that was fed with the same diet only during the dark phase. The locomotor activity and calorie intake (Figure 1) together with the body temperature (Figure 2) were measured for mice.

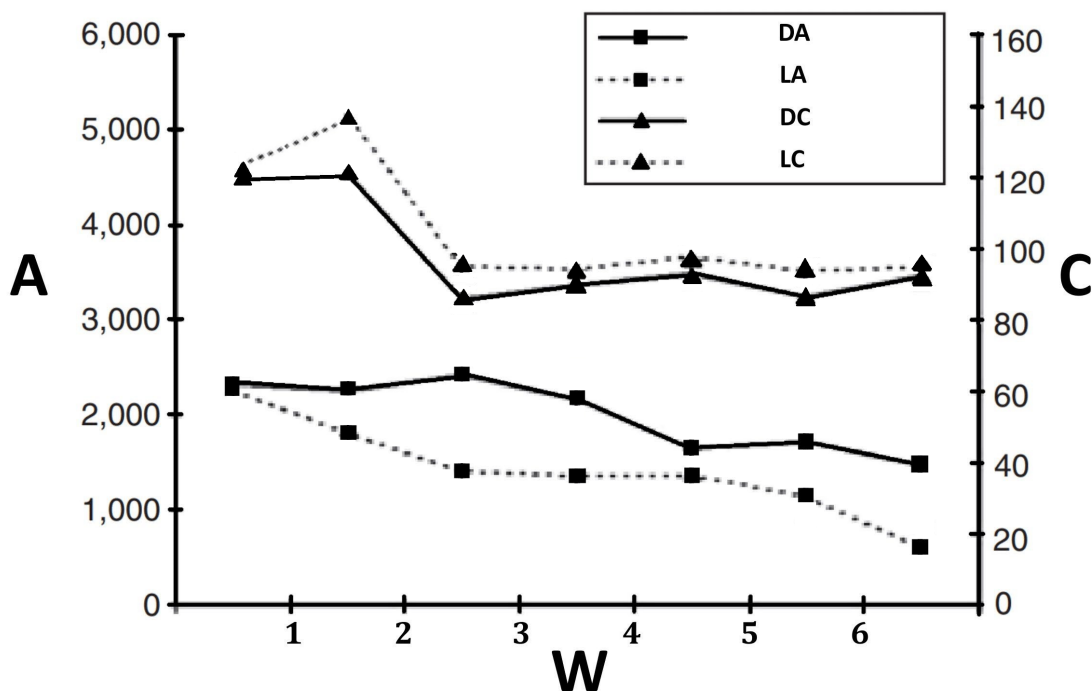


Figure 1. A – weekly locomotor activity counts, C – caloric intake in kcal, W – time in weeks, DA – dark-fed mice activity, LA – light-fed mice activity, DC – dark-fed mice calories, LC – light-fed mice calories.

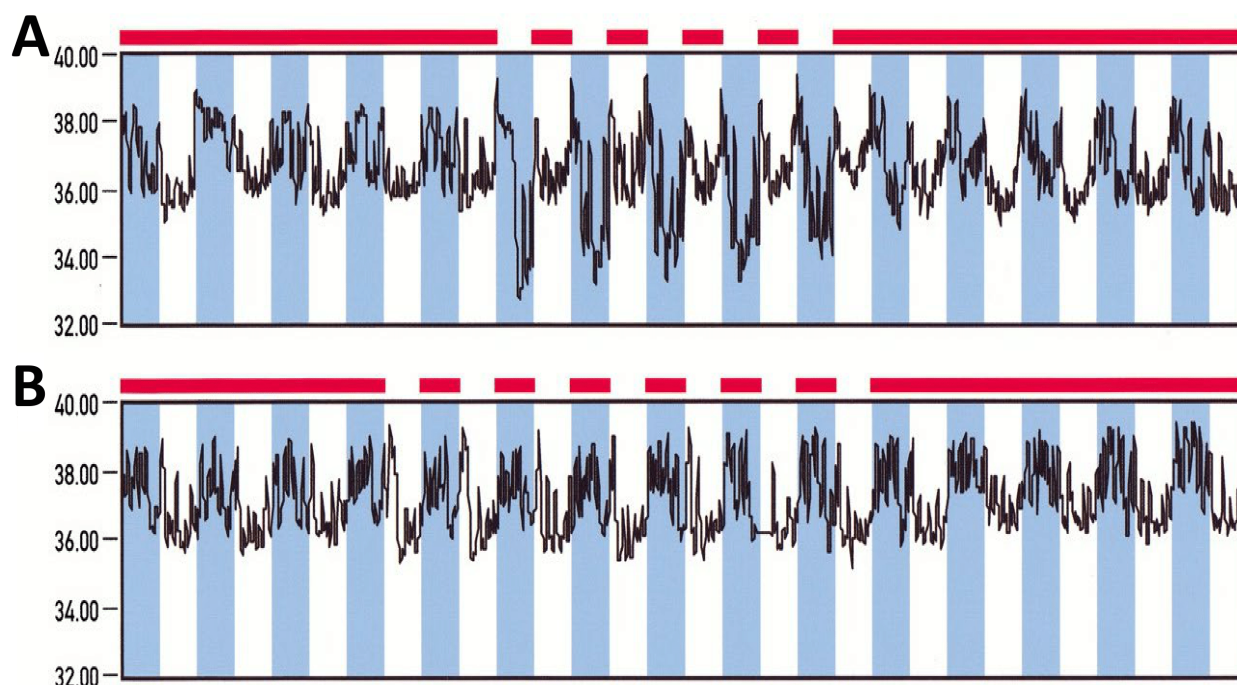


Figure 2. Recordings of body temperature of the two mice groups fed during the light (**A**) for 5 days and dark (**B**) for 7 days phases. The feeding periods are indicated by solid bars on top of the panels. The dark phases are depicted in blue.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. We can expect light-fed mice to have higher body weight than dark-fed mice.

B. Night-time feeding is an example of circadian-behavior misalignment in mice.

C. Night-time feeding altered the circadian body temperature range stronger than light-time feeding.

D. It can be concluded that the decrease in locomotor activity in light-fed mice occurs due to reduced calorie intake.

41

In *Octopus laqueus*, two distinct sleep stages are observed: active (AS) and quiet (QS). Active sleep is marked by active bouts, which include only specific body and eye movements along with transitions in skin patterns, occurring between periods of quiet sleep. There are potential parallels between vertebrates' non-REM and REM (Rapid Eye Movement) sleep phases and octopuses' QS and AS stages, respectively. Researchers measured the occurrence of active bouts in the group of octopuses during the day and night and in the interrupted conditions as seen in Figure 1.

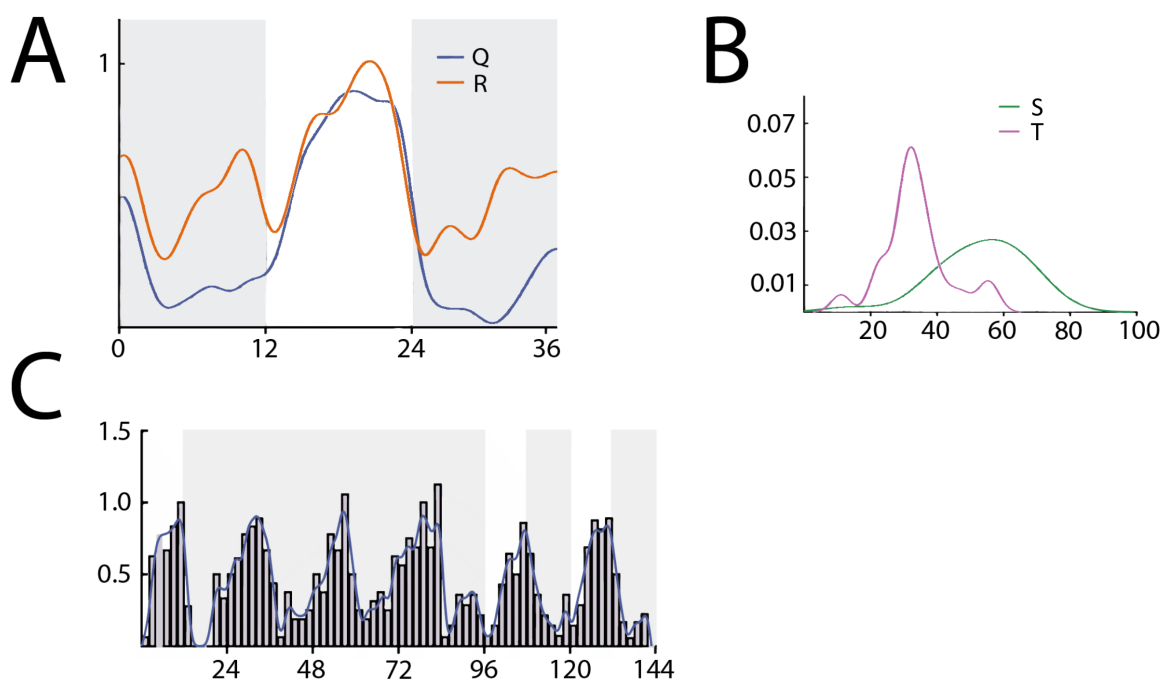


Figure 1. **A** Average number of active bouts per hour over 36 hours before (Q) and after (R) 2-day sleep deprivation (darkness is depicted in gray background areas). **B** Probability of the next bout (Y-axis) occurring N minutes after (X-axis) a normal (S) or interrupted (T) bout. **C** Active bouts per hour (Y-axis) during 3 days of constant darkness (darkness is depicted in gray background areas).

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. Bouts are more likely to be controlled by internal circadian mechanisms than by external environmental signals.

B. On average, octopuses of this species have 8 active bouts per night.

C. The data shows that sleep deprivation in this octopus species increases the average duration of an active bout.

D. Active bouts can be replenished if they do not occur in the normal amount.

42

Electric eels (*Electrophorus electricus*) are predatory fish that utilize electrical and mechanical signals during hunting. They emit two types of electrical impulses: low-voltage, which induces sudden muscle contraction of the prey, and high-voltage, which paralyzes the prey, aiding in capture and consumption.

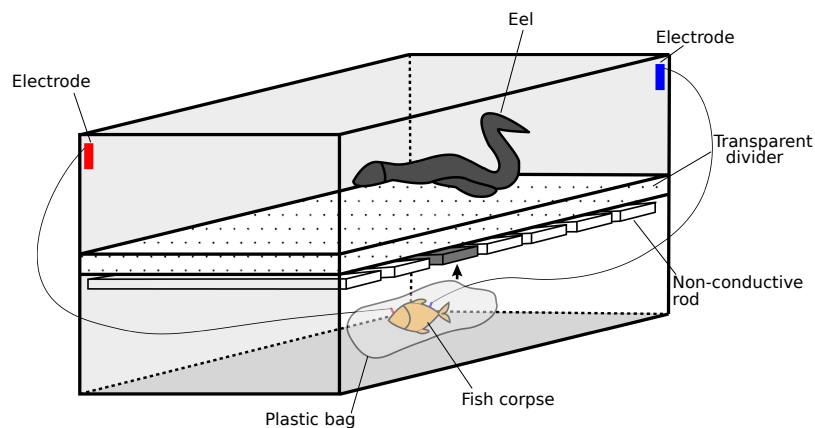


Figure 1. Experiment setup; black arrow - conductive rod.

In the experiment conducted for studying electrolocation mechanisms of eels, a container with two compartments was used, as shown in Figure 1. The lower compartment contained an isolated fresh fish corpse attached to electrodes, connecting it to the upper compartment's environment. Additionally, several electrically non-conductive rods and one conductive rod were placed beneath the transparent, perforated divider.

Results of the experiment indicated that upon placement in the container, the eel began attacking the conductive rod, but not the fish corpse (Figure 2). Assume that the fish corpse was supplied with a sufficient amount of ATP.

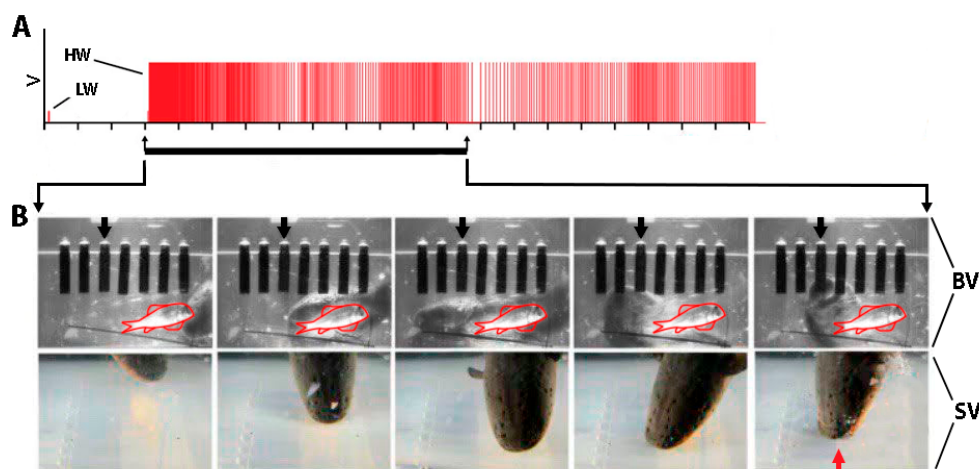


Figure 2. **A** Impulses recorded from the upper compartment (x-axis - time, y-axis - voltage); LW - low voltage impulse, HW - high voltage impulse. **B** Frames shot from the experiment (BV - bottom view, SV - side view); black arrow - conductive rod, red arrow - attack. The fish corpse is highlighted in red.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Only low-voltage impulses are required for prey electrolocation.
- B.** The divider blocked the movement of water between the compartments.
- C.** The first frame in Figure 2B was taken before the corpse began to contract.
- D.** Eels prefer to rely on their mechanoreceptors rather than electroreceptors when localizing the exact location of their prey.

43

Saigas (*Saiga tatarica*) are herding antelopes that have an enlarged nasal cavity. Figure 1 below shows computed tomographic (CT) sections of their head.

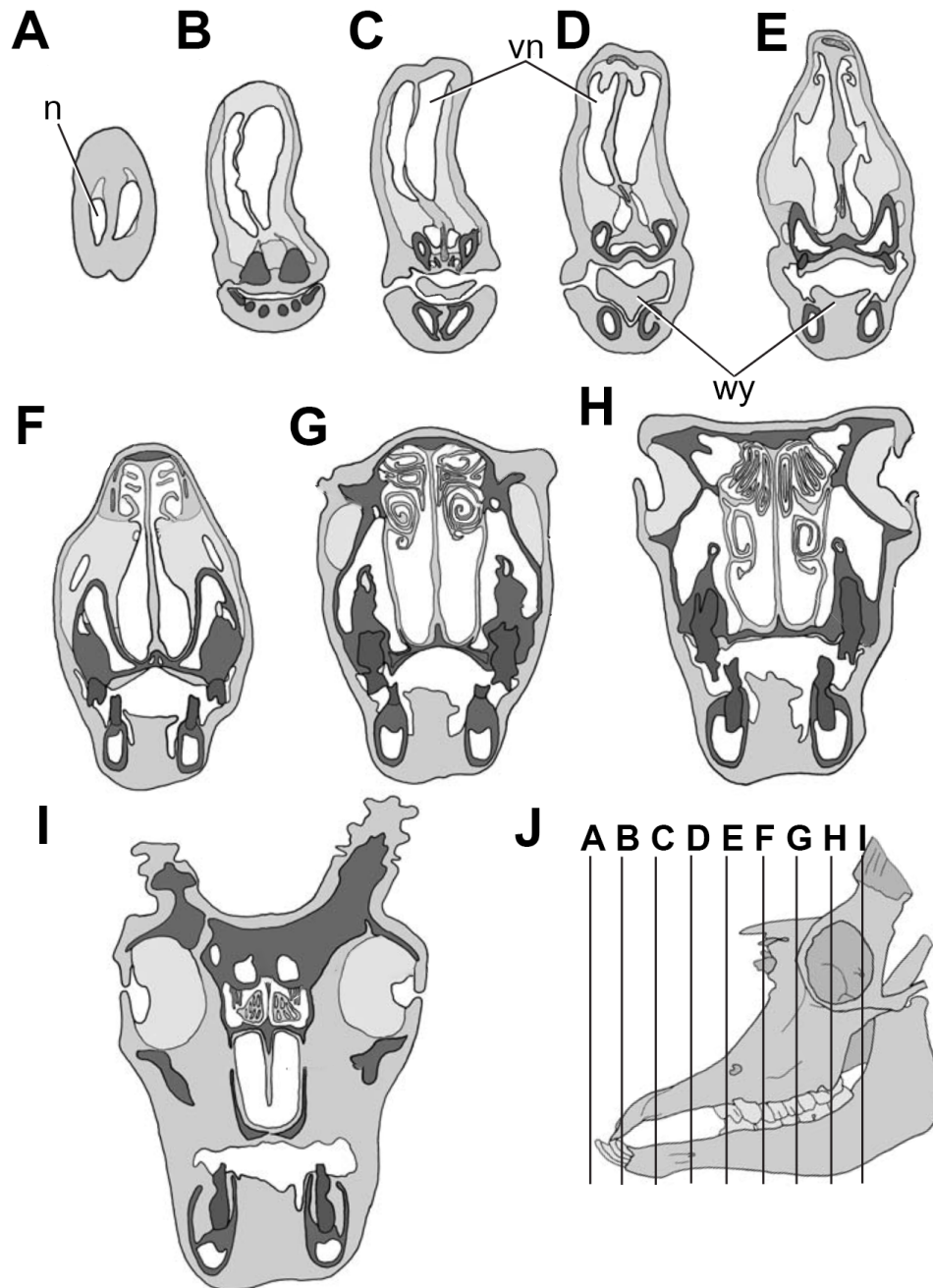


Figure 1. Internal structures of the saiga head in successive CT transverse sections. J - lateral view of the skull to show the levels of the sections shown in A-I.

Theoretical Exam - Part A



Q7-9

English (Official)

The main natural enemy of saigas is the wolf. However, in open areas, saigas are not afraid of wolves because of difference in their running speeds: saigas – 75-80 km/h, wolves – 40-45 km/h. At the same time, the weight load per 1 cm² for the saiga is 500 grams, while it is 160 grams for the wolf.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** The bones at sections A-I correspond only to the darkest areas.
- B.** Linear flow rate of air in the nostrils ("n" in figure A) is lower than the linear flow rate of air in the nasal cavity (vn) in section C.
- C.** The main function of the structure "wy" in figures (D) and (E) is to remove dust particles from the air.
- D.** Wolves hunt saigas more successfully in summer than in the snowy winter.

44

Approximately 50% of epididymal sperm express Toll-like receptors 7/8 (TLR7/8), which are encoded on the X chromosome. The researchers investigated the effects of their activation in mice sperm cells by a specific ligand - R848. To do that they performed several experiments consisting of a swim-up method and in vitro fertilization (IVF). The obtained data is presented below.

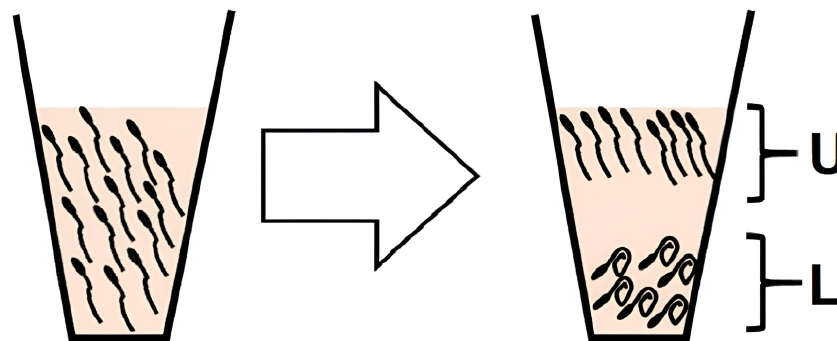


Figure 1. Swim-up method - technique designed to sort spermatozoa by motility and the capability to swim upwards in the tube out of the seminal plasma; U - upper layer, L - lower layer.

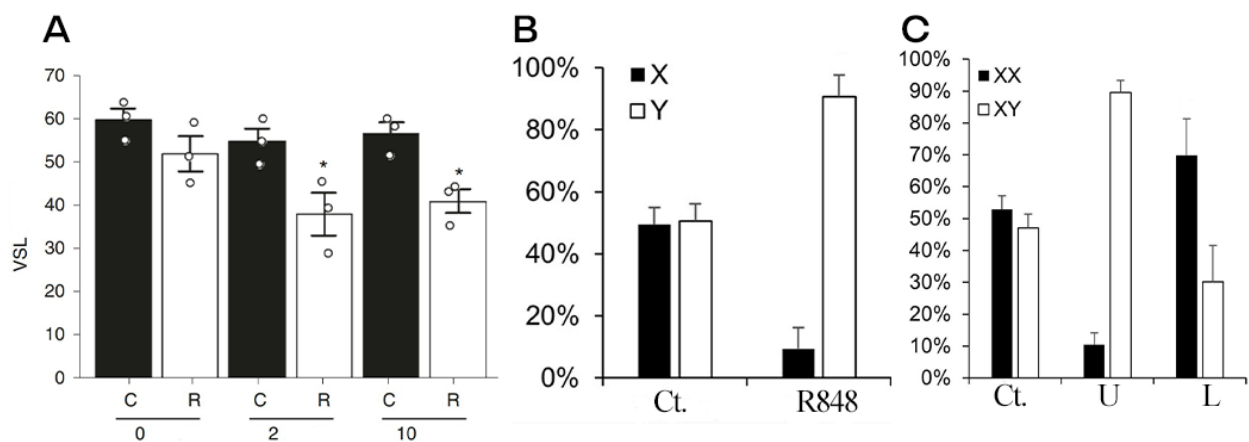


Figure 2. **A** Comparison of straight-line velocity (VSL) of spermatozoa in different glucose concentrations (mM) without (C) and with (R) R848. '*' - significant difference between C and R. **B** Distribution of X chromosome- and Y chromosome-bearing spermatozoa in the upper layer without (Ct.) and with R848. **C** Comparison of sex of the embryos obtained from IVF with untreated sperm cells (Ct.) in contrast to sperm cells from the upper (U) and lower (L) layers of the swim-up test tube separated after treatment with R848.



On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Activation of TLR7/8 on sperm cells increases their motility.
- B.** Following IVF using the high-mobility sperm, more than 80% of the embryos were XY.
- C.** Ligand activation of TLR7/8 together with the swim-up method could be used to sort X chromosome- and Y chromosome-bearing sperm cells.
- D.** The significant effect of the TLR7/8 activation on sperm motility is observed only in the presence of glucose.

45

To create vascularised tissue in vitro, transgenic rat cardiac cells expressing luciferase were co-cultured with or without endothelial cells (EC) and fibroblast growth factor 2 (FGF-2). Luciferase - an enzyme that catalyzes the reaction of luciferin to emit bioluminescent light. To mimic in vivo conditions, the newly created cardiac tissue was placed on a vascular bed to ensure a media supply (Figure 1A). Media supply through the new blood vessels was assessed via fluorescence antibody staining for EC (Figure 1B). Then, luciferin was infused from the vascular bed side, and bioluminescence was measured in the cardiac cells (Figure 1C).

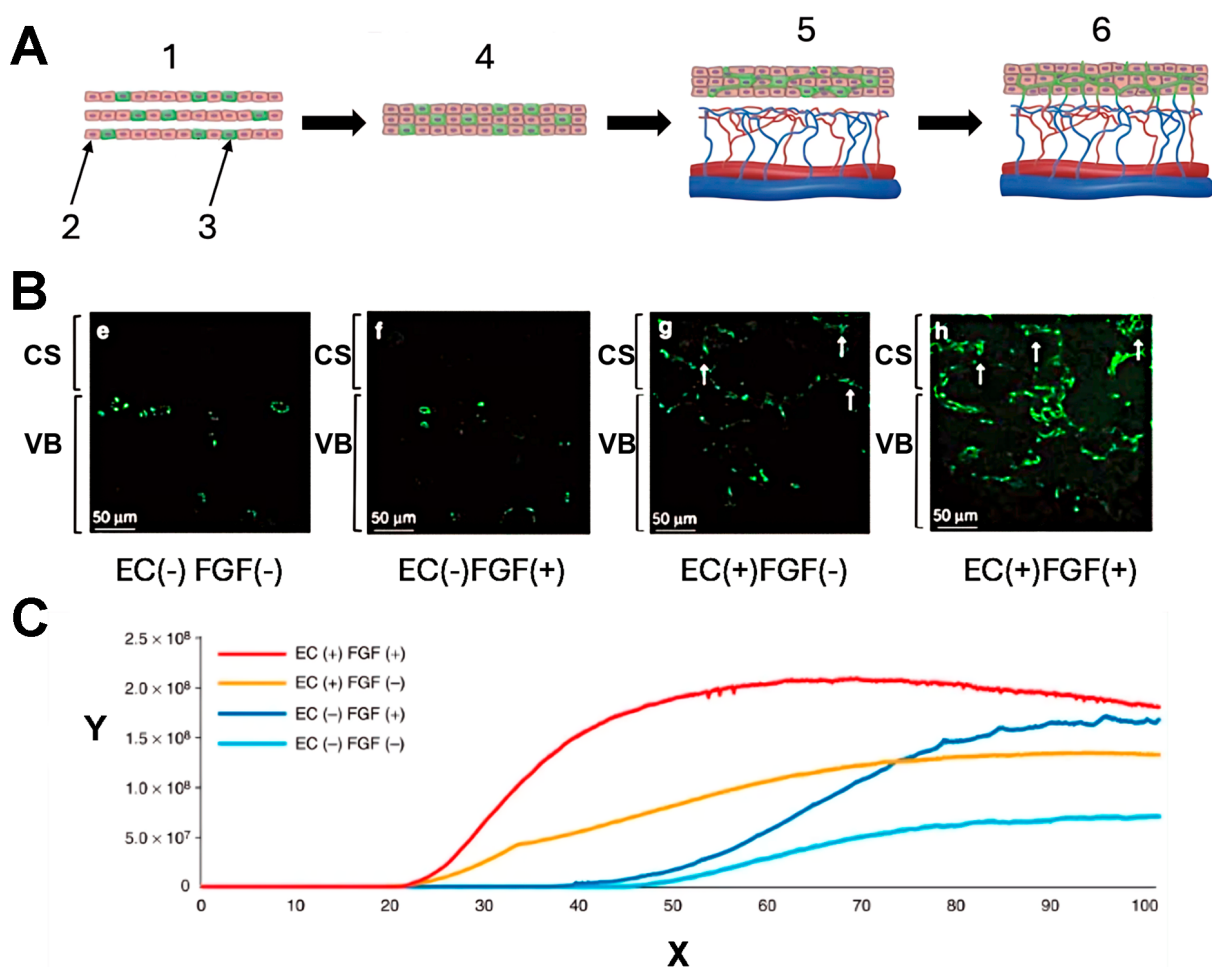


Figure 1. **A** 1 - EC co-cultured cardiac cell sheet, 2 - cardiac cells, 3 - endothelial cells, 4 - layered cell sheets, 5 - cell sheets overlaid on a vascular bed, 6 - organised vascular network. **B** White arrows show EC; CS - cell sheet, VB - vascular bed. **C** X - Time (min), Y - Bioluminescence (photons per second).

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Endothelial cell co-culturing increases the development of blood vessels in tissue.
- B.** FGF-2 inhibits the migration and proliferation of endothelial cells.
- C.** Assuming identical proliferation rates across all tissues, EC(-) FGF(+) tissues demonstrate higher cell survival compared to EC(+) FGF(-) tissues.
- D.** The high rate of bioluminescence for EC(+) FGF(+), can be explained mainly by direct diffusion of the media from the vascular bed through the tissue layers.

46

The discovery of light-gated cation channels quickly led to the development of new tools and applications, notably the optical control of neural activity using algal channel rhodopsin-2 (ChR2).

Viral vectors were used to express ChR2 in rat hippocampal neurons, and ChR2 membrane localization was observed. A series of experiments was conducted to investigate the properties of these transduced cells, and the resulting data are presented below.

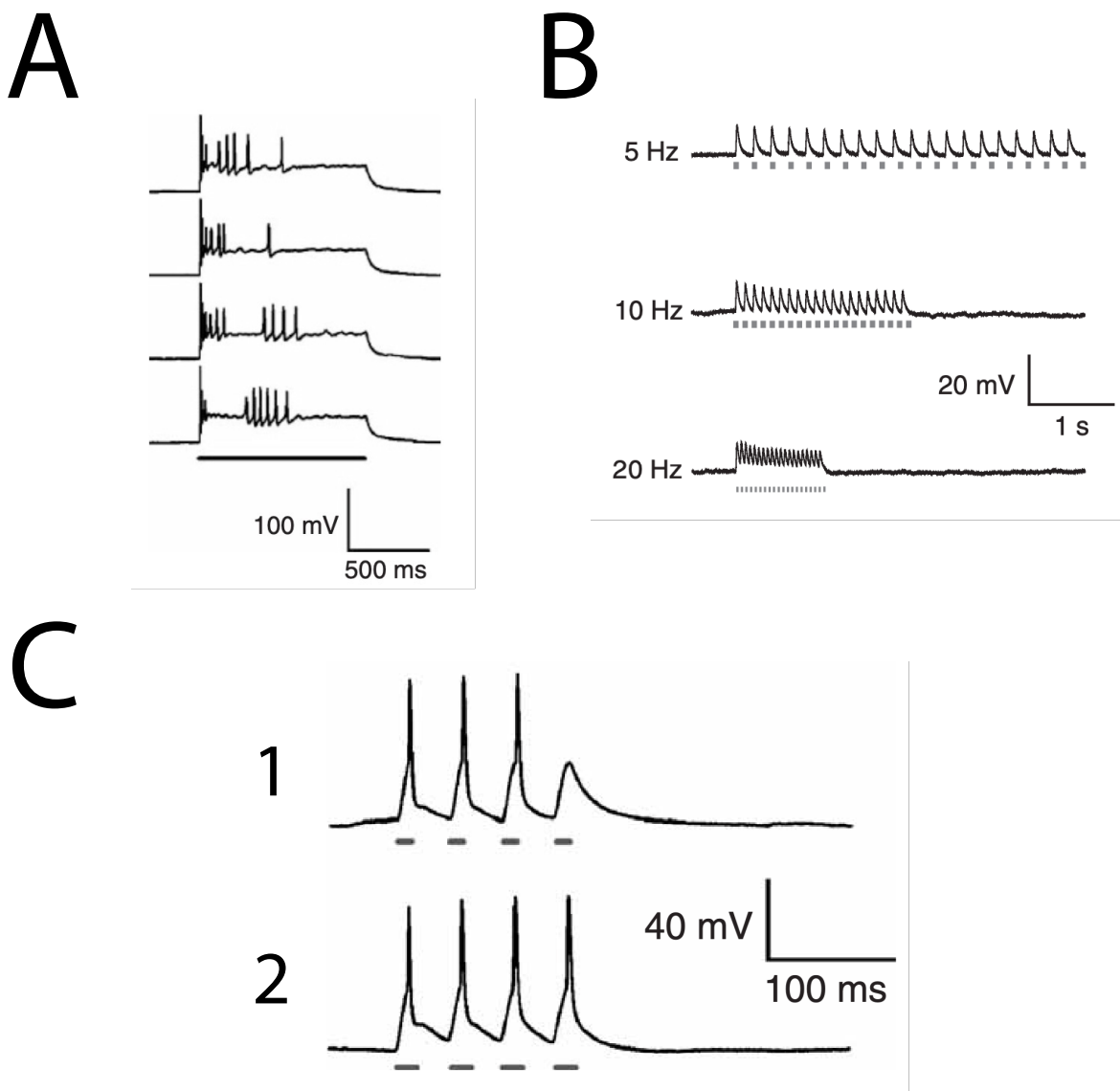


Figure 1. **A** Voltage traces and spikes in a hippocampal neuron evoked by 1-second periods of light (4 repeated experiments). **B** Voltage traces showing subthreshold depolarizations in response to light pulses. **C** Voltage traces in response to brief light pulse series. Bars below the records indicate light pulses.



On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** During steady illumination, the consistency of spikes is limited by the neuron's action potential firing frequency limit.
- B.** There is no action potential initiated during the fourth stimulation in **C1** due to the absolute refractory period of the neuron.
- C.** Light-induced depolarization would happen regardless of whether ChR2 is selective for sodium alone or both sodium and potassium.
- D.** Consistent induction of subthreshold depolarizations, compared to action potentials, requires more precise tuning of the light pulse length.

47

The efficiency of animal locomotion can be expressed in terms of the cost of transport (COT), derived from oxygen consumption versus velocity data. The oxygen consumption plot represents the amount of energy required to achieve and maintain a certain speed. COT represents how efficiently an organism can cover a unit distance at a certain speed, and generally has the same trendline shape among different animals and different gaits of the single animal species.

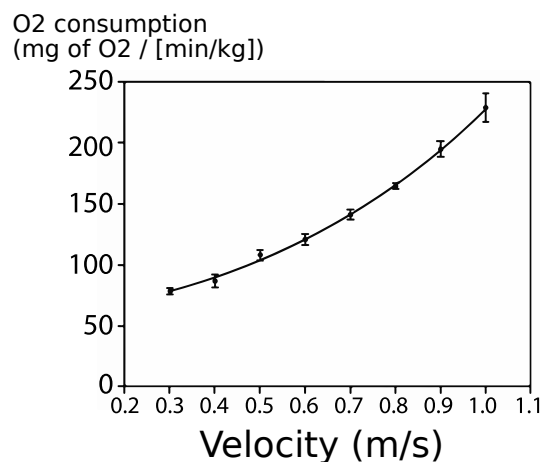


Figure 1. Oxygen consumption versus velocity graph for cod (fish).

$$\text{COT} = a + bV + cV^2$$

Coefficients for cod: $a = 0.17$; $b = -0.22$; $c = 0.14$.

Table 1. Trendline equation for COT (V is in km/h) and list of coefficients suiting data obtained from cod.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Flying birds would have a lower oxygen consumption at minimum moving speed on oxygen consumption versus velocity graph than a cod of comparable size.
- B.** The minimum possible COT of the cod is achieved at 0.6 km/h.
- C.** If you sample the speeds at which a large population of horses move during the week, you would see that all speeds fall within a single, narrow range.
- D.** For animals that run, the oxygen consumption versus velocity plot for running would be more linear than the cod's.

48

During pulmonary function tests, tidal volume, inspiratory reserve volume, and expiratory reserve volume can be measured directly, but not residual volume (RV). The helium dilution technique estimates RV (Figure 1), by recording V_{sf} (final spirometer volume) and C2 (final helium concentration). The initial spirometer volume is 5L with 10% helium. Helium is not exchanged in the lungs, i.e. not absorbed into the blood.

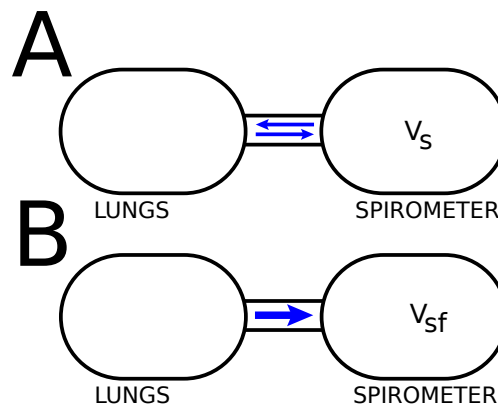


Figure 1. **A** In the first stage, the patient is attached to the spirometer after regular expiration and then breathes several times to establish helium equilibrium. V_s - initial spirometer volume. **B** The patient performs a full forced expiration, and the spirometer is detached.

Patients	V_{sf} (L)	C2 (%)
Healthy control	6.1	6.8
1	5.6	6.5
2	5.6	8

Table 1. Results of the helium dilution test for two male patients and one male control.

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** V_{sf} equals to V_s plus expiratory reserve volume.
- B.** Patient 2 has an RV of 750 ml.
- C.** Given that inspiratory capacity is constant for Patient 1, the increase in RV with respect to the healthy control can be explained by an increase in lung volume.
- D.** A patient with a single-lung pneumothorax, causing incomplete lung collapse, would likely have results similar to Patient 2.

49

Esophageal Doppler Monitoring (EDM) is a minimally invasive method to measure blood flow in the aorta and assess cardiac output. A Doppler probe is inserted into the esophagus near the aorta. The principle behind the measurement is the detection of changes in frequency (Doppler shift) of ultrasound waves reflected by moving red blood cells. Using the Doppler effect, described by the following equation, the probe calculates blood flow velocity.

$$\Delta f = \frac{2vf_0 \cos \theta}{c_s} \quad (1)$$

where

$$\cos \theta = \frac{\sqrt{2}}{2}, c_s = 1540 \text{ m/s}, f_0 = 4 \text{ MHz} \quad (2)$$

The resulting waveform provides important data on heart function, such as stroke volume and cardiac output, which helps guide clinical decisions in real-time.

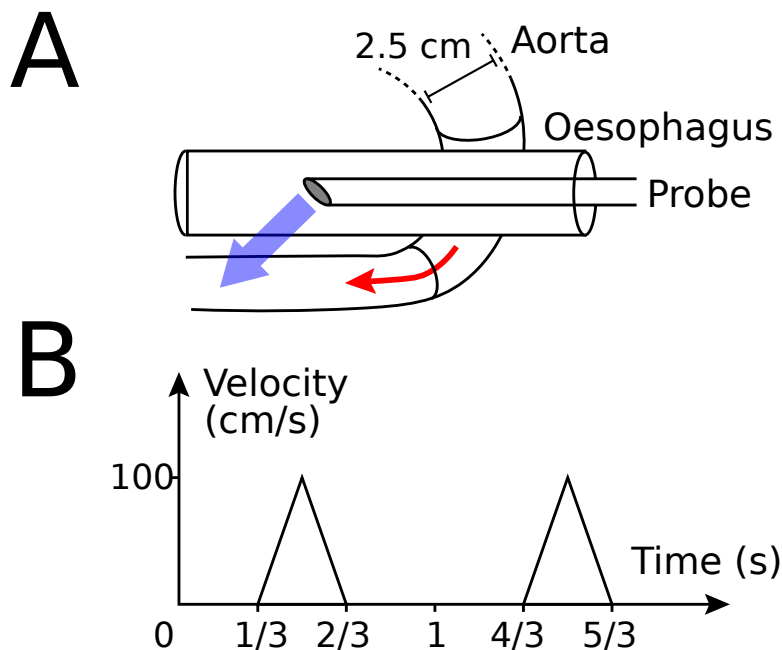


Figure 1. **A** Placement of the Doppler probe in the esophagus near the aorta to measure blood flow velocity (red arrow). **B** Doppler waveform showing linear blood velocity (cm/s) over time (s), with a peak systolic velocity of 100 cm/s. The area under the curve shows the distance traveled by blood.



On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** Tachycardia decreases the intervals between waveforms on the velocity-time graph.
- B.** Without any compensation from the heart, high arterial resistance increases peak velocity.
- C.** If the largest frequency shift observed for a patient was 4.4 kHz, their peak velocity is around 120 cm/s
- D.** According to Figure 1B and 1A, a person's heart ejects 4.9 L of blood per minute.

50

The countercurrent system is a common biological pattern, classified into countercurrent multipliers and exchangers. In vertebrates, these systems often involve a specialized network of arteries and veins lying close together, known as the rete mirabile. In humans, an example of this system is found in the kidneys, where the nephron and vasa recta together form a countercurrent multiplier. This arrangement allows for efficient exchange and concentration of solutes and water, which are crucial in urine concentration and maintaining the body's fluid balance.

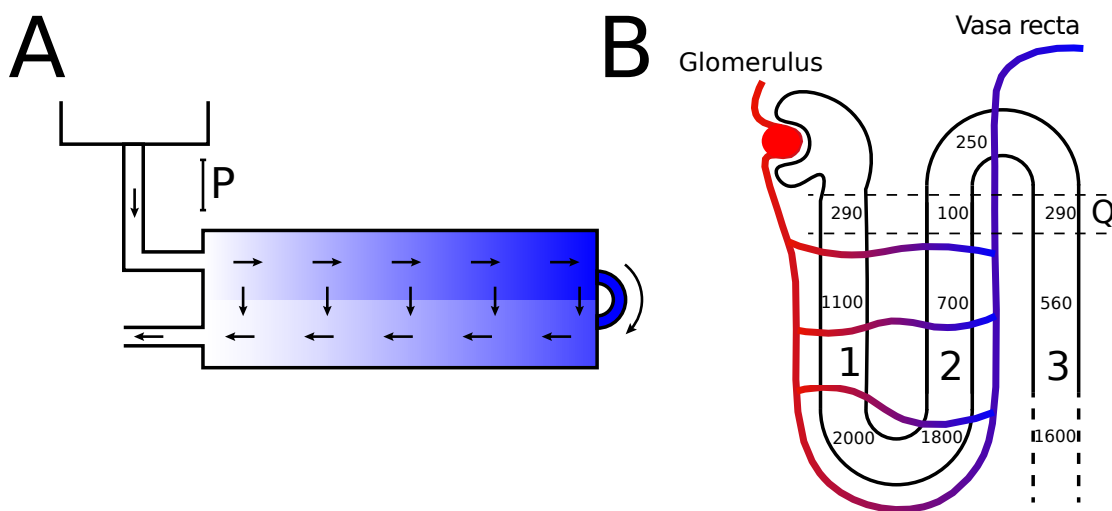


Figure 1. **A** Countercurrent osmotic multiplier: solute passes through a reservoir separated by a semipermeable membrane; black arrows show water movement driven by pressure P. **B** Nephron diagram: 1 - descending limb, 2 - ascending limb, 3 - collecting duct. Numbers indicate osmolarity (mOsmol/kg).

On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

A. Water movement across the membrane in the countercurrent multiplier (Figure 1A) and loop of Henle is primarily driven by the similar forces.

B. Sodium reabsorption explains the difference in osmolarity between the descending limb and the collecting duct.

C. The osmolarity in region Q in the tissues surrounding the tubules is between 100 and 290 mOsmol/kg.

D. Blood entering the vasa recta in region Q has higher osmolarity than blood leaving the vasa recta in region Q.

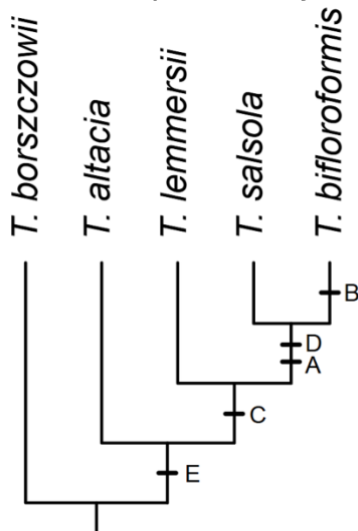
Solutions and Sources for the IBO 2024 Theoretical Exams

Exam A

Biosystematics

Task #1.

- . **FALSE.** Explained by a figure.
- . **FALSE.** Explained by a figure.
- . **TRUE.** They are monocotyledons.
- . **TRUE.** Explained by a figure.



References:

<https://www.plantarium.ru/lang/en/page/image/id/799657.html>
<https://www.plantarium.ru/lang/en/page/image/id/767164.html>
<https://www.plantarium.ru/lang/en/page/image/id/52277.html>
<https://www.plantarium.ru/lang/en/page/image/id/565448.html>
<https://www.plantarium.ru/lang/en/page/image/id/199306.html>

Task #2.

- . **TRUE.** By employing deductive reasoning and systematically listing options, one can logically identify each of the five owl species displayed on the table. If the process is executed accurately, it becomes evident that the fifth species belongs to the *Surnia* genus (*Surnia ulula*), which is the sole representative of its kind.
- . **FALSE.** The second most related pair is 3/5 with 2. (1 - *Asio*, 2 - *Athene*, 3 - *Glaucidium*, 4 - *Otus*, 5 - *Surnia Ulula*).
- . **FALSE.** All species belong to different genera.
- . **TRUE.** If the most recent common ancestor of the *Pulsatrix*-*Meagascop* clade lived in Africa / Eurasia, that would require 2 events of migration to America as well as two events of extinction in Africa and Eurasia. In the opposite case (common ancestor lived in America), we need to assume only a single migration from America to Africa / Eurasia.

References:

https://en.wikipedia.org/wiki/Long-eared_owl

https://en.wikipedia.org/wiki/Pallid_scops_owl

https://en.wikipedia.org/wiki/Eurasian_pygmy_owl

https://en.wikipedia.org/wiki/Northern_hawk-owl

https://en.wikipedia.org/wiki/Little_owl

<https://www.bird-phylogeny.de/superorders/strigiformes/>

Task #3.

- . **TRUE.** . The most parsimonious solution for alignment I is the topology depicted on phylogenetic tree 1 (5 changes across the tree in total). Note, it is given that D is an outgroup.
- . **FALSE.** . Sites 3 and 5 are not useful. Site #3 is identical for all taxa. While site #5 has one variation - taxon C has A (not T), it is not helpful for the phylogenetic reconstruction via parsimony - you just need to make one change that leads to the taxon C (T → A) and it'll be the most parsimonious solution for for any tree topology.
- . **FALSE.** . Phylogenetic tree 1 is incongruent with the reference tree, while RNA polymerase β is a known conserved gene in Bacteria compared to transposase gene that is part of the transposons.

- **FALSE.** . As species D is an outgroup, the remaining three taxa can be phylogenetic related in three possible ways - D,A,(B,C); D,B,(A,C); D,C,(A,B)

Cell and Molecular Biology

Task #4.

- **FALSE.** Since oxygen consumption is higher in tumor cells, we can conclude that they have elevated metabolism. They need to consume more oxygen because of a relatively high proliferation rate.
- **TRUE.** The differences in extracellular pH values can be explained by abnormally elevated rates of anaerobic glycolysis in tumor cells, which results in higher production and accumulation of lactic acid. This phenomenon is known as the Warburg effect.
- **FALSE.** Figure 2 demonstrates that the oxygen consumption rate is elevated in tumor cells. Such a high demand can't be satisfied, which leads to the development of hypoxia in the tumor microenvironment.
- **FALSE.** Error bars of the data in Figure 2 demonstrate that the cancer cells of patient 2 display the most variation in the single-cell OCR. Hence, they are more heterogeneous compared to the cells of other patients.

Reference:

[1]<https://pubs.rsc.org/en/content/articlehtml/2018/ra/c8ra02095g#cit10>
(Figure1)

[2]<https://www.nature.com/articles/s41551-019-0376-5> (Figure 2)

[3]<https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/acid-base-homeostasis#:~:text=It%20is%20well%20documented%20that,between%200.035%20and%200.045%20mEq>

[4]<https://aacrjournals.org/cancerres/article/73/5/1524/586608/Acidity-Generated-by-the-Tumor-Microenvironment>

Task #5.

- **TRUE.** Tyr-33 substituted for aromatic amino acids such as tryptophan and phenylalanine shows higher affinity values than for other mutants.
- **FALSE.** In Figure 1A.1, it can be seen that the original amino acid Asn has a higher affinity to all cardiac glycoside molecules than all mutants.
- **TRUE.** The substitutions Tyr-33-Trp and Trp-100-Arg show the highest absorbance ratios in their mutations. Therefore, they can be used for cardiac glycoside detection systems.
- **TRUE.** Digoxigenin lacking sugar in R1 behaves differently from other glycosides.

Reference:

Burks, E. A., Chen, G., Georgiou, G., & Iverson, B. L. (1997). In vitro scanning saturation mutagenesis of an antibody binding pocket. *Proceedings of the National Academy of Sciences of the United States of America*, 94(2), 412–417. <https://doi.org/10.1073/pnas.94.2.412>

Task #6.

- **FALSE.** The structure (a) in Figure 1D has Φ and ψ angles of about -100 and 120 degrees, respectively. It is mostly located in Region 1 in Figure 2.
- **FALSE.** The structure (b) in Figure 1D has Φ and ψ angles of about -60 and -60 degrees, respectively. It is mostly located in Region 2 in Figure 2.
- **TRUE.** The structure (c) in Figure 1D has Φ and ψ angles of 90 and -90 degrees, respectively. From the Ramachandran plot, it can be seen that amino acids with Φ and ψ angles of 90 and -90 degrees are uncommon.
- **TRUE.** From the Ramachandran plot, it can be seen that amino acids with Φ and ψ angles of 0 degrees are not present in the rabbit's pyruvate kinase. They are prohibited by steric interference between atoms in the polypeptide backbone and amino acid side chains.

Reference:

Nelson, D. L., & Cox, M. M. (2008). *Lehninger principles of biochemistry* (5th ed.). W.H. Freeman.

Task #7.

- . **TRUE.** Actively dividing cells that need R5P for nucleotide synthesis. The reactions catalyzed after the first TKT-catalyzed reaction use R5P, which is essentially needed for cells to divide fast. Therefore, only the reactions before the first TKT-catalyzed reaction are more active (than the reactions occurring after the first TKT-catalyzed reaction) in fast-growing cells.
- . **FALSE.** From the reaction pathways, it can be seen that TKT transfers two-carbon fragments.
- . **TRUE.** With G6PDH deficiency less NADPH will be produced. Also, ROS will be reduced by existing NADPH, leading to a decreased level of NADPH.
- . **FALSE.** From the reaction scheme, it is seen that for the production of two molecules of F6P three G6P are needed.

References:

Jin L, Zhou Y. Crucial role of the pentose phosphate pathway in malignant tumors. *Oncol Lett.* 2019 May;17(5):4213-4221. doi: 10.3892/ol.2019.10112. Epub 2019 Mar 5. PMID: 30944616; PMCID: PMC6444344.

Lee, M., Malloy, C., Corbin, I., Li, J., & Jin, E. (2019). PPP and carbon rearrangement. [Photograph]. Wiley Analytical Science. <https://analyticalsciencejournals.onlinelibrary.wiley.com/cms/asset/98de01c5-8738-44e0-87f2-02ea397c2b4c/nbm4096-fig-0001-m.png>

Nelson, D. L., & Cox, M. M. (2008). *Lehninger principles of biochemistry* (5th ed.). W.H. Freeman.

Bozdech, Z., & Ginsburg, H. (2005). Different modes of PPP action. [Photograph]. *Malaria Journal*. https://media.springernature.com/lw685/springer-static/image/art%3A10.1186%2F1475-2875-4-17/MediaObjects/12936_2005_Article_133_Fig2_HTML.jpg?as=webp

Task #8.

- **FALSE.** Pictures A and B show that all the bases of all loops are in the same place - therefore each of the CTCFs participates in more than one loop. Picture A shows formation of 2 or 3 loops, if each CTCF-binding site would only participate in one loop, maximum number of loops would be 2.
- **FALSE.** DNA methylation prevents protein binding (CTCF in this case), thus only 2 loops are formed instead of 3. The site by which a new loop is formed corresponds to the 3rd CTCF site.
- **TRUE.** Expression activity of IGF2 depends on the proximity of enhancer, figures A and B imply that this enhancer is located between H19 gene and CTCF binding site 4. Expression of H19 depends on the methylation state of ICR - it is located close to its promoter and in the methylated state transcription factors cannot access DNA.
- **TRUE.** As was mentioned in the previous explanation, expression of H19 depends on the methylation state of its promoter, which overlaps with the ICR, regardless of the enhancer.

Reference:

Nativio, R., Wendt, K. S., Ito, Y., Huddleston, J. E., Uribe-Lewis, S., Woodfine, K., ... & Murrell, A. (2009). Cohesin is required for higher-order chromatin conformation at the imprinted IGF2-H19 locus. **PLoS genetics**, **5**(11), e1000739.

<https://doi.org/10.1371/journal.pgen.1000739>

Task #9

- **TRUE.** Since cryo-EM works by averaging many low-resolution images of molecules, a region that is different among these images will be not clear in the final density map and that means that this region is more flexible or has more stable conformations.
- **FALSE.** From the molecular model, we can see that these helices are holding subunits of ATAD1 together. One side of the helix should have hydrophobic residues to interact with another subunit, another side should be hydrophilic to interact with water.

- **FALSE.** The specificity of the substrate is mainly affected if the central pore has mutations, we see that E193Q is clearly outside of the pore.
- **FALSE.** ATAD1 indeed translocates proteins, it can be deduced from the motion of M6 and overall structure, however, it pulls mislocalized transmembrane proteins out of the membrane. This conclusion is made from fluorescent assay (Gos28 is in the membrane) and structure of pore (aromatic amino acids).

Reference:

Lan Wang, Hannah Toutkoushian, Vladislav Belyy, Claire Y Kokontis, Peter Walter (2022) Conserved structural elements specialize ATAD1 as a membrane protein extraction machine eLife 11:e73941
<https://doi.org/10.7554/eLife.73941>

Task #10

- **FALSE.** The shortest possible path is movements along a vertical line, the real benefit of having magnetosomes is in energy efficiency - bacteria are not spending any energy to align themselves on path towards OATZ (even if this path is not the most efficient).
- **FALSE.** Since the polarity of cells is opposite on both hemispheres, the movement of flagella will be the same for bacteria from the southern hemisphere.
- **TRUE.** Since axial magnetotactic bacteria do not follow the direction of the field they have two options for movement - to the left and the right.
- **FALSE.** The situation describing the beginning of the experiment is bacteria below a certain depth level in figure B. As we can see bacteria move and rotate their flagella clockwise. In the setup C there is no oxygen in the middle and concentration increases towards the ends.

References:

Bazylinski, D., Frankel, R. Magnetosome formation in prokaryotes. Nat Rev Microbiol 2, 217–230 (2004). <https://doi.org/10.1038/nrmicro842>
 Arash Komeili et al. ,Magnetosomes Are Cell Membrane Invaginations Organized by the Actin-Like Protein MamK. Science 311, 242-245 (2006).
<https://doi.org/10.1126/science.1123231>

Task #11

- . **FALSE.** Library construction is necessary to make variance, which is one of the important criteria for natural/artificial selection.
- . **FALSE.** Anaerobic conditions for cultivation are necessary to avoid usage of electron transport chains for the NAD⁺ regeneration.
- . **TRUE.** The only connection of this heterologous reaction catalyzed by Enzyme D to native metabolic network is NAD⁺/NADH usage. Otherwise, the selection pressure cannot affect the enzyme D.
- . **TRUE.** As the oxygen concentration in the large intestine is very low, the strains having higher Enzyme D activity have higher NAD⁺ regeneration rate at the anaerobic conditions, which is the case in the large intestine.

Reference:

<https://doi.org/10.1038/s41467-021-27266-9>

Task #12

- . **TRUE.** DMSO₂ is a less hydrophilic molecule than DMSO, and it is stable compared to DMSO₄ (which rapidly hydrolyses in water).
- . **TRUE.** DMSO is a strongly hydrophobic compound used as a solvent for organic molecules and an agent facilitating penetration of organic membranes, including skin.
- . **FALSE.** Gibbs free energy (which includes enthalpy) influences the feasibility of the reaction, but the reaction rate is the function of the activation energy.
- . **FALSE.** Methastases block most of the elimination of the DMSO and its derivatives, however, as was mentioned in the text odor was observed indicating elimination through the lungs.

References:

Grant, P. M., Haas, J. S., Whipple, R. E., & Andresen, B. D. (1997). A possible chemical explanation for the events associated with the death of Gloria Ramirez at Riverside General Hospital. *Forensic science international*, 87(3), 219-237.

Ecology

Task #13

- . **FALSE.** Both NK+ graphs for legume cover are marked with a dot, which means they are both statistically significant.
- . **FALSE.** Biomass graphs only differ in magnitude between 3 years and 6 years.
- . **TRUE.** Every time there is added nitrogen, the legumes cover, species richness, or biomass on average decline. That is not true for other nutrients, in which legumes do not have a competitive advantage of fixation. Therefore, steppes must indeed be nitrogen-limited, as taking away nitrogen advantage lead to negative effects for the species with that advantage.
- . **TRUE.** Non-nitrogen fixers do not benefit from low soil nitrogen, so any additional nutrients will drive their growth.

Reference:

Pedro M. Tognetti, et al. "Negative effects of nitrogen override positive effects of phosphorus on grassland legumes worldwide". Proceedings of the National Academy of Sciences 118. 28(2021): e2023718118.

Task #14

- . **TRUE.** According to the hypothesis C, the tropics have a higher range of ages which would increase the variance in the species age. The temperate zone has less variance due to their later starting point of diversification.
- . **TRUE.** This means that a pattern has been established regardless of the starting point of diversification caused by the global catastrophe.
- . **FALSE.** Greater seasonal variation is in the temperate zone. And if it increases the diversification rate in the temperate zone this would go against Hypothesis B.
- . **TRUE.** This implies that all taxa emerged initially in the tropical regions and specific diversification of temperate species started after the start of the tropical diversification.

References:

Mittelbach, G. G., Schemske, D. W., Cornell, H. V., Allen, A. P., Brown, J. M., Bush, M. B., ... & Turelli, M. (2007). Evolution and the latitudinal diversity gradient: speciation, extinction and biogeography. *Ecology letters*, 10(4), 315-331. <https://doi.org/10.1111/j.1461-0248.2007.01020.x>

Task #15

- . **TRUE.** When warm and moist air becomes cold, excess moisture is released as precipitation, and increased precipitation leads to larger gross primary production.
- . **FALSE.** It is La Niña because it will cause an increase in precipitation over Australia (western Pacific region).
- . **FALSE.** During El Niño, wind over the Pacific decreases, and the depth of transition between warm and cold water increases, due to this upwelling decrease.
- . **FALSE.** Changes in year Y are caused by a decrease in salinity of a lake which is caused by increased precipitation. Increased precipitation over North America is possible when El Niño happens.

Reference:

Ryan, J. P., Ueki, I., Chao, Y., Zhang, H., Polito, P. S., and Chavez, F. P. (2006), Western Pacific modulation of large phytoplankton blooms in the central and eastern equatorial Pacific, **J. Geophys. Res.**, 111, G02013, <https://doi.org/10.1029/2005JG000084>

Wurtsbaugh, W. . (1992). Food-web modification by an invertebrate predator in the Great Salt Lake (USA). **Oecologia**, 89*(2), 168–175. <https://doi.org/10.1007/BF00317215>

Cairns, S. C., & Grigg, G. C. (1993). Population Dynamics of Red Kangaroos (*Macropus rufus*) in Relation to Rainfall in the South Australian Pastoral Zone. **Journal of Applied Ecology**, 30*(3), 444–458. <https://doi.org/10.2307/2404185>

Task #16

- . **FALSE.** Here slope depends on d in the equation, since d is the complexity of the pattern it will have a larger value for rough coastlines
- . **FALSE.** Since the graph is on a logarithmic scale, there will be more individuals with smaller scales than individuals of average species, even if there are only half of them.
- . **FALSE.** This scale depends on the resources or territory required for each individual, not the size of the individual.
- . **TRUE.** In herds, the perspective scale of each individual would depend on the overall perspective scale of the entire herd.

Reference:

Milne, B. T. 1993. Pattern analysis for landscape evaluation and characterization. In M. E. Jensen and P. S. Bourgeron, eds. Ecosystem Management: Principles and Applications.

Task #17

- . **TRUE.** Water withdrawal increases the speed of water circulation and water molecules travel faster among water reservoirs
- . **FALSE.** While high Rws always represent a water crisis, low Rws can be explained by a water crisis caused by an inability to utilize available $RFWR$ (large Q and small W).
- . **TRUE.** Map with $1/Aw$ will have weighted values of population and water availability and thus some regions with small population density would have opposite values in $1/Aw$ and Rws
- . **TRUE.** Food and industrial goods production requires much more water than is required for consumption by humans and thus represents a major water

References:

Taikan Oki, Shinjiro Kanae, Global Hydrological Cycles and World Water Resources. *Science* 313, 1068-1072 (2006). DOI:10.1126/science.1128845

Ethology

Task #18

- . **TRUE.** In the case of Western Barn Owls, failing to respond to potentially lethal warnings is perhaps because they are used to hunting, not getting hunted, and alarming sounds such as approaching vehicles are new to them.
- . **FALSE.** The speeding behavior allows them to exploit traffic gaps for a period when traffic volume is low. The plateau represents a steady increase of probability of mortality associated with the speeding behavior.
- . **TRUE.** When traffic has reached sufficient volume for an animal to pause before attempting crossing, the probability of avoidance becomes greater than the probability of mortality.
- . **FALSE.** Even slight traffic volume can restrict movement of avoiders leading to the lowest mortality among others.

References:

https://www.fs.usda.gov/psw/publications/jacobson/psw_2016_jacobson001.pdf

Task #19

- . **TRUE.** Information about effective routes is passed from generation to generation
- . **TRUE.** In each generation of the experimental group, each new pigeon requires time to learn the route before showing actual performance
- . **TRUE.** If it would not, there will be no increase in efficiency over generations in the experimental group, which can be explained by “innovations” introduced by a new pigeon in a pair
- . **TRUE.** Collective decision making increases with the number of animals in the group, but figures show clear difference between experimental and control pair performance, while both of them contain 2 pigeons

Reference:

Sasaki, T., Biro, D. Cumulative culture can emerge from collective intelligence in animal groups. Nat Commun 8, 15049 (2017).
<https://doi.org/10.1038/ncomms15049>

Genetics & Evolution**Task #20**

. **FALSE.**

p: A1

q: A2

r: A3

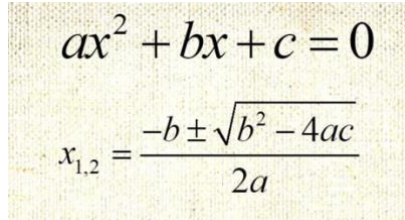
$p+q+r = 1$

$p^2+q^2+r^2+2pq+2pr+2qr = 1$

$A_3A_3 = r^2 = 0,01$; $r = 0,1$

$A_2_ = q^2+2qr = 0,08$

$q^2+2qr+0,08 = 0$; $q = 0,2$



$$ax^2 + bx + c = 0$$

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$r = 0,1$; $q = 0,2$; $p = 0,7$

So individual in n generation make up 70%

B. **TRUE.** A2A2 and A2A3

B. **FALSE.** Meiosis does not ensure the distribution of two sets of chromosomes (paternal and maternal) at 50% in the haploid daughter cell.

B. **FALSE.** A lethal mutation most likely will not be able to pass through the haploid generation, since it will not be covered by a dominant allele

References:

Campbell biology, 10th edition, Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson (2014), Pearson

Task #21

- . **FALSE.** . More genetically diverse populations have larger effective population sizes.
- . **TRUE.** . As the African population has higher genetic diversity, the deleterious (or slightly deleterious) mutations are less likely to get fixed (frequency = 1) as the selection plays greater role comparatively to the genetic drift.
- . **TRUE.** . Since humans started expansion out of Africa, different geographic regions were colonized by different population groups. As a result, all new populations were established by a small number of people from a larger (African) population.
- . **FALSE.** . As human genomes are almost identical to each other, including conserved DNA polymerases, the opposite is true and the heterozygosity is best studied in highly variable regions, such as microsatellites.

References:

Li, J. Z., Absher, D. M., Tang, H., Southwick, A. M., Casto, A. M., Ramachandran, S., ... & Myers, R. M. (2008). Worldwide human relationships inferred from genome-wide patterns of variation. *science*, 319(5866), 1100-1104.

McClellan, J. M., Lehner, T., & King, M. C. (2017). Gene discovery for complex traits: lessons from Africa. *Cell*, 171(2), 261-264.

Task #22

- . **FALSE.** The high consumed amount of exogenous ethanol is a consequence of agricultural output i.e. cultivation of certain crops and their intended fermentation, therefore, prior to the extensive development of agriculture, ADH was adjusted to degrade only tiny amounts of endogenous or exogenous alcohol.
- . **TRUE.** The adverse effect of acetaldehyde accumulation in the body is going to discourage individuals from ethanol consumption.

- . **FALSE.** There is a lack of information to claim that, but the evident low frequency of ADH1B*2 gives a clue for absent ethanol consumption-driven positive selection.
- . **TRUE.** With the given information, the assumption of positive selection geographically correlates with the presence of supposed selective force.

References:

- <https://cyberleninka.ru/article/n/etnogeneticheskie-osobennosti-ustoychivosti-organizma-k-alkogolyu-v-populyatsiyah-narodov-severa/viewer>
- <https://www.semanticscholar.org/paper/Distribution-of-the-alcohol-dehydrogenase-allele-in-Borinskaya-Kal'ina/c96185fa0f8e1ac6c89a50b3a1df0eb68b2a9446>
- <https://drosophila4schools.wordpress.com/alcohol/>
- <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2823730/>

Task #23

- . **FALSE.** . The frequency of A1 converges to the ~0.3-0.35 and remains relatively stable, suggesting that selection favors the intermediate genotype (stabilizing selection). The tricky part of the question is that while frequency of A2A2 > A1A2, the relative fitness of A2A2 < A1A2 that is why the populations converge to stable equilibrium. If relative fitness of A2A2 > A1A2, then allele A1 would go extinct over time.
- . **FALSE.** . As the random fluctuations from generation to generation are more pronounced, it suggests that Aizhan decreased the population size in experiment #2 (genetic drift starts playing a more important role, increasing overall stochasticity due to the random chance).
- . **TRUE.** . Almost all populations (including the theoretical fit) reach some degree of the stable equilibrium, suggesting the heterozygote advantage (it can be actually easily derived from Hardy-Weinberg equilibrium).
- . **FALSE.** . The frequency of A1 decreases below 0.5 before reaching some degree of stability, indicating that relative fitness of genotypes is the following one: A1A2>A2A2>A1A1

Task #24

- . **TRUE.** . Ribosomal proteins are essential and universally highly expressed, as translation is the fundamental cellular process. Hence, ribosomal genes tend to have very high codon usage bias to synthesize ribosomal proteins rapidly and efficiently by utilizing the most abundant tRNA pool.
- . **TRUE.** . As codon usage bias tends to improve the translational efficiency, correction of the transgenic DNA to account for that phenomenon generally leads to more efficient expression of it by the recipient's organism.
- . **FALSE.** . Viruses tend to have a pronounced codon usage bias. Furthermore, even when viruses don't carry their tRNA molecules, they still rely on their host translational machinery and tRNA. Hence, genetic material of viruses will be selected to fit their host tRNA pool. In addition, multiple phages (bacterial viruses) can also carry their own tRNA molecules to account for their codons content. (multiple explanations possible, not only tRNAs)
- . **FALSE.** . Methionine cannot have codon usage bias as it is made only from one codon.

Reference:

Plotkin, J. B., & Kudla, G. (2011). Synonymous but not the same: the causes and consequences of codon bias. *Nature Reviews Genetics*, 12(1), 32-42.

Task #25

- . **FALSE.** As it can be seen from the figure 2b, the mutation X is located near to the amino acids that are less conserved rather than the mutation Z, which is located in a highly conservative region. As the active site of an enzyme is crucial for its function, the active sites are likely to be more conserved.
- . **FALSE.** The genetic code for Threonine (Thr) is AC_, and for Alanine (Ala), it is GC_. Assuming single-nucleotide changes in the mutations, the deduced mutation of A → G leads to the genetic code GC_ for Thr. Given that both A and G are purines, this mutation is identified as a transition

(purine → purine or pyrimidine → pyrimidine), not a transversion (A/G → T/C).

- . **FALSE.** It can be observed that the two subunits possess MTS, indicating that they are transported into the mitochondrion separately. This suggests that the assembly of RNase takes place within the mitochondrion rather than externally before transport.
- . **TRUE.** We know that individual II-3 (A1) is the carrier of mutation X. We need to find the probability that individual II-2 (A2) is a carrier of mutation Y, which is 2/3. The probability of them having a child with the syndrome is 1/4. Therefore, the overall probability of them having a child with the syndrome is $2/3 * 1/4 = 1/6$.

References:

Smith, T.B., Rea, A., Thomas, H.B. et al. Novel homozygous variants in PRORP expand the genotypic spectrum of combined oxidative phosphorylation deficiency 54. Eur J Hum Genet 31, 1190–1194 (2023). <https://doi.org/10.1038/s41431-023-01437-2>

Bhatta, A., Dienemann, C., Cramer, P. et al. Structural basis of RNA processing by human mitochondrial RNase P. Nat Struct Mol Biol 28, 713–723 (2021). <https://doi.org/10.1038/s41594-021-00637-y>

Task #26

- . **TRUE.** Since it is not crossing the threshold line and we see a much longer duration, we can conclude that the nature of the event at the Frasnian-Famennian boundary (FF on the graph) is not the same as all other mass extinctions.
- . **FALSE.** Based on smaller events graph can be biased, however absence of large recent events supports the general trend.
- . **TRUE.** Events above that line mean large mass of carbon added in a short period of time, almost all events over that line are mass extinctions
- . **TRUE.** Since there are more species and they are more efficient, carbon travels faster between reservoirs, and carbon perturbation events happen in a shorter time scale.

Reference:

Daniel H. Rothman ,Thresholds of catastrophe in the Earth system.Sci. Adv.3,e1700906(2017).DOI:10.1126/sciadv.1700906

Task #27

- . **TRUE.** The efficiency of E104K and G238S increases significantly when they are combined.
- . **FALSE.** Cumulative probability plot is skewed to the right, meaning that trajectories have decreasing probabilities with trajectory 1 being the most probable.
- . **FALSE.** Phenotypic fitness does not influence mutation rate but increases the probability of mutation fixation.
- . **FALSE.** If there will be intermediate form with high fitness and next forms have decreasing fitness, then this route is not always the most probable, regardless of the final fitness. If there will be local fitness maxima evolution would not favor further mutations decreasing fitness (evolution cannot plan).

References:

Daniel M. Weinreich et al. ,Darwinian Evolution Can Follow Only Very Few Mutational Paths to Fitter Proteins.Science312,111-114(2006).DOI:10.1126/science.1123539

Task #28

- . **TRUE.** Effectively neutral mutations, while may not be truly neutral, have negligible effect on the scales of real populations (usually $> N_e$) => their fixation can be explained only by random genetic drift. For example, suppose, $s < 1/N_e$, e.g. humans ($N_e = 10000$) => $s < 1 \cdot 10^{-4}$ (meaning that mutation has a very weak effect so that it is effectively neutral (cannot be efficiently selected within the actual population - its fate completely depends on drift))
- . **TRUE.** Species with larger N_e have less effectively neutral mutations and consequently larger amounts of weakly adaptive mutations.

- . **TRUE.** We are not able to track one large group of deleterious mutations - lethal mutations since only survivors are passing their mutations.
- . **FALSE.** It represents the proportion of effectively neutral mutations, when we compare genomes deleterious mutations should be under negative selection and not present in large amounts - we mostly see effectively neutral mutations at non-silent sites.

References:

Eyre-Walker, A., Keightley, P. The distribution of fitness effects of new mutations. *Nat Rev Genet* 8, 610–618 (2007). <https://doi.org/10.1038/nrg2146>

Task #29

- . **TRUE.** Only infection of germline cells will generate heritable genetic element
- . **FALSE.** Loss of one gene, for example - env, is enough to lose the property of virion formation and to become a retrotransposon
- . **FALSE.** Since LTR regions are similar, they are prone to homologous recombination events, where everything between them is lost
- . **TRUE.** This factor would prevent certain retrovirus from infecting the host and when the exogenous retroviral population becomes too small or extinct, then the population no longer needs this ERV in their genome

References:

Johnson, W.E. Origins and evolutionary consequences of ancient endogenous retroviruses. *Nat Rev Microbiol* 17, 355–370 (2019). <https://doi.org/10.1038/s41579-019-0189-2>

Plant Anatomy and Physiology

Task #30

- . **FALSE.** From Figure 1, it's evident that when a shoot from a wild-type plant is grafted onto the root of a gibberellin-deficient plant, there are no observable changes. However, when a *ga1-3* shoot is grafted onto a *ga1-3* root, there's a decrease in intensity, indicating that gibberellin synthesis occurs in the shoots and is transported to the roots.
- . **TRUE.** Examining Figure 2 reveals that the wild type exhibits a high concentration of gibberellin in the vacuoles of the pericycle and a relatively low concentration in the endoderm. This pattern is consistent across all mutants except the last one, where the ability to store gibberellin in the vacuole is compromised. Notably, in this mutant, the cytoplasmic concentration of gibberellin in the endoderm and cortex is significantly higher than that of the wild type. This indicates that gibberellin, instead of being stored in the vacuole, is being transported into the endodermal cells, resulting in an elevated concentration. This observation underscores the regulatory role of vacuoles in gibberellin secretion into the endoderm and cortex.
- . **TRUE.** This mutant exhibits impaired gibberellin transport into the endodermis, resulting in a low level of suberization in these cells. Since endodermal suberization is crucial for the formation of Casparian strips, this mutant will have poorly defined Casparian strips. This will lead to an increase in apoplastic transport into the stele, which increases the chances of obtaining water imbalance or toxin contamination.
- . **FALSE.** The transporter *npf 2.14* is located on the vacuolar membrane. This can be observed in Figure 2, where its absence resulted in a reduction of vacuolar gibberellin concentration to zero.

References:

<https://doi.org/10.1038/s41477-023-01391-3>

Task #31

- . **TRUE.** Because GDC, a decarboxylase, removes a CO₂, but does not prevent serine production. Serine can go into gluconeogenesis.
- . **FALSE.** Increased CO₂ levels will lead to Rubisco favoring photosynthesis over photorespiration, so LESS need for the latter.
- . **FALSE.** All enzymes there are either pink or yellow, so overexpressing them would have a negative net effect.
- . **TRUE.** Because their Calvin cycle happens in cells with high concentration of CO₂.

Reference:

Stefan Timm, Martin Hagemann, Photorespiration—how is it regulated and how does it regulate overall plant metabolism?, Journal of Experimental Botany, Volume 71, Issue 14, 6 July 2020, Pages 3955–3965, <https://doi.org/10.1093/jxb/eraa183>
https://commons.wikimedia.org/wiki/File:Photorespiration_allgemein.svg

Task #32

- . **TRUE.** Because electrodes could trigger hyperpolarization or depolarization, bypassing light stimuli and causing stomatal opening/closing.
- . **FALSE.** Lignin makes cells more rigid, preventing subsidiary cells from properly "bending" to allow a wide opening, thus making stomata narrower and less effective.
- . **FALSE.** Potassium deficiency would lead to lower volume of water flow, as potassium gradients would have lower magnitude, so the cell shape would change less and pore area would be lower
- . **TRUE.** Since aquaporins are passive channels, they cannot start or end a flow on their own, so adding more of them could only increase the rate of osmosis.

Reference:

T.D.G. Nunes, D. Zhang, M.T. Raissig Form, development and function of grass stomata Plant J., 101 (4) (2020), pp. 780-799

Task #33

- . **TRUE.** Without the xanthophyll cycle, the plants cannot dissipate excess light's energy. Therefore, they will suffer strong oxidative stress under the sun, and would prefer shade.
- . **TRUE.** The Steppe population is constantly exposed to direct sunlight, while the understory population is hidden by the forest canopy. Therefore, the former would be more adapted to constant daylight, partially through higher xanthophyll concentration. As it is a temperate climate, extra heat does not make this a maladaptive trait.
- . **FALSE.** High leaf temperature means that using heat as an energy dispersion mechanism is more dangerous, and just reducing de-epoxidase activity would not help as under sunlight the proton concentration would increase regardless, activating more zeaxanthin. Thus, total Pre-Z + Z concentration should be decreased for the plant to survive. Since the climate is always sunny and hot, it is a viable adaptation.
- . **TRUE.** This is a hypothetical scenario, but if no other option was available, the leaves from the top of the canopy would have to produce more ascorbate (salt of ascorbic acid, also known as vitamin C) to adapt to higher light levels. Thus, eating them gives more vitamin C. From the book: "The pool of reduced ascorbate, which plays a role in the xanthophyll cycle (Fig. 2.17), is also several-fold greater in plants acclimated to high light (Logan et al. 1996)." page 45

References:

Lambers, H., & Oliveira, R. S. (2019). Photosynthesis, Respiration, and Long-Distance Transport. In Plant Physiological Ecology. Springer Nature.

Task #34

- . **FALSE.** By 9am, both starch and soluble sugar graphs had positive change for all three stages. Therefore, photosynthesis must have begun before that, as it is the sole source of production of new starch and soluble sugars for photosynthetic cells.

- . **TRUE.** Peak value of 120 instead of 72-90 is unlikely to come due to grains growing the seed. TSC is easier to transport through phloem towards the seeds compared to starch, so there is an increased demand for TSC in seed kernels.
- . **TRUE.** Since the TSC pool includes free cytosolic glucose, which is the fuel for cell respiration, this should be true. Between 24 and 6 hours, that glucose is going to be respired further, reconnecting the graphs.
- . **FALSE.** Lower leaf starch means more carbohydrates are leaving leaves to go to the seed's endosperm. Since it is a crop, humans will eventually consume endosperm and thus, more starch going to the endosperm is a beneficial trait.

References:

Liang, X., Gao, Z., Zhang, L., Shen, S., Zhao, X., Liu, Y., Zhou, L., Paul, M. J., & Zhou, S. (2019). Seasonal and diurnal patterns of non-structural carbohydrates in source and sink tissues in field maize. BMC Plant Biology, 19(1). <https://doi.org/10.1186/s12870-019-2068-4>

Task #35

- . **TRUE.** Density is inversely proportional to PC3, and *S. giganteum* has lower PC3 values than the other species.
- . **FALSE.** Resistance to xylem blockage is tracked by PC2, and height is tracked by dot size. For *S. sempervirens*, dot size and PC2 are positively correlated, so it is the taller trees that would have higher resistance to xylem blockage
- . **TRUE.** In an arid environment—adapted plants, controlling transpiration through changes in leaf shape and structure is a more advantageous tactic to costly branch-level changes to xylem structure. Therefore, the change of the environment to a wetter one will allow the plants to pursue the costlier strategy.
- . **FALSE.** To compare density and height, we compare the dot size and PC3. Bigger dots tend to be close to 0.5 mark for PC3, and smaller dots cluster at higher PC3. However, they also intermix with big dots near 0.5, so PC3 (density) and dot size (height) don't appear particularly covarying at all. Furthermore, density inversely covarying with height does not

make biological sense, as taller trees would want denser, more flexible and taut stems.

References:

Ambrose, A. R., Sillett, S. C., & Dawson, T. E. (2009). Effects of tree height on branch hydraulics, leaf structure and gas exchange in California redwoods. *Plant Cell and Environment*, 32(7), 743–757. <https://doi.org/10.1111/j.1365-3040.2009.01950.x>

Task #36

- . **FALSE.** Since diffusion coefficient in water is smaller than air, the aquatic plants prefer thinner cuticles to allow more area to uptake/release the dissolved gasses, as opposed to only stomata of land plants.
- . **TRUE.** The graph between 7 and 8 shows that HCO_3^- is at least 90% of total carbon in that range of pH, so it would be advantageous to use it as a carbon source in oceanic ecosystems.
- . **TRUE.** True, because it would locally lower the pH to levels where CO_2 dominates and can be more readily uptaken as opposed to its ionic forms.
- . **TRUE.** Higher efficiency Rubisco would lead to higher forward reaction rate, which would create the asymmetry to give direction to carbonic anhydrase reaction. This assumes the pH stays close enough to its original value, which is possible because cytoplasm is buffered and anhydrase does not consume enough protons to shift the pH too far.

References:

Lambers, H., & Oliveira, R. S. (2019). Photosynthesis, Respiration, and Long-Distance Transport. In *Plant Physiological Ecology*. Springer Nature.

Task #37

- . **FALSE.** This refers to the Casparian belts, which do not allow water and solutes to pass through the cell walls (apoplastic pathway), only through cell membranes. Casparian belts are located in the endoderm, that is, on the border of zones B and C.
- . **FALSE.** In order for water to flow from the soil (zone A) to the primary root cortex (zone B), a solution with a higher concentration of dissolved substances must be formed in zone B (that is, in zone B the water potential must be lower). Solutes combine with water molecules due to their charge, reducing the concentration of free water molecules. Thus, for the shown water flow, it is necessary that the concentration of free water molecules in zone B be less than in zone A.
- . **TRUE.** Oxygen starvation usually occurs during floods. As a result of the described process, empty cavities appear in zone B (primary root cortex), which improves the aeration of root tissues.
- . **TRUE.** True, because NaCl dissociates in water into two particles. That is, 0.2 moles of NaCl yield 0.4 Osm/L in solution. Thus, the solution will have a higher concentration of dissolved particles than the cells in zone B (i.e., it will be more concentrated).

References:

Campbell Biology, chapter 36 "Resource acquisition and Transport in Vascular Plants"

https://en.wikipedia.org/wiki/Osmotic_concentration

Animal Anatomy and Physiology

Task #38

- . **FALSE.** The SA node should have its own pace - C3. C1 corresponds to the ventricular myocyte and C2 to the atrial one.
- . **FALSE.** Repolarization of atria is not visible behind the QRS complex, it would be seen if there is no depolarization of ventricles.
- . **FALSE.** S wave is depolarization, but moving in the opposite to the lead side.

- . **TRUE.** The current direction of the vector P corresponds to the direction of the lead II and is perpendicular to the lead III.

References:

Hamid Khederlou, H. (2023). Complete heart block associated with paraneoplastic hypercalcemia: A case report. *European Heart Journal*, 7(1). <https://doi.org/10.1093/ehjcr/ytac492>

Morlin, M. T., Cruz, C. J. G., Melo, P. B. S., Lopes, G. H. R., Soares, E. M. K. V. K., Porto, L. G. G., & Molina, G. E. (2020). BRADYCARDIA IN ATHLETES: DOES THE TYPE OF SPORT MAKE ANY DIFFERENCE? – A SYSTEMATIC REVIEW. *SciELO Brazil*, 26(5). https://doi.org/10.1590/1517-8692202026052019_0001

Silverthorn, D. U. (2022). *Human physiology an integrated approach* (11th ed.). Pearson, Harlow.

Teymouri, N., Mesbah, S., Navabian, S. M. H., Shekouh, D., Najafabadi, M. M., Norouzkhani, N., Poudineh, M., Qadirifard, M. S., Mehrtabar, S., & Deravi, N. (2022). ECG frequency changes in potassium disorders: a narrative review. *American journal of cardiovascular disease*, 12(3), 112–124

Widemaier, E. P., Vander, A. J., Raff, H., & Strang, K. T. (2019). *Vander's human physiology: The mechanisms of body function* (15th ed.). McGraw-Hill Education.

Task #39

- . **FALSE.** Snow leopards' hemoglobin shows almost no sensitivity to DPG, as evidenced by nearly identical curves for cofactor-free hemoglobin and hemoglobin with added DPG, unlike the noticeable difference seen in humans between cofactor-free and DPG-added hemoglobin (Figure 1B).
- . **TRUE.** The hemoglobin of snow leopards inhabiting high-altitude areas has a low affinity to oxygen and causes hypoxia. An enhanced capacity to increase ventilation under severe hypoxia could help compensate for the low O₂ affinity of snow leopards, causing respiratory alkalosis. This, in turn, induces increased renal excretion of bicarbonate compared to snow leopards living in lowland areas, returning the pH back to normal.
- . **FALSE.** From Figures 1A and 1B, it can be observed that the oxygen affinity of hemoglobin in snow leopards is mostly the same as in lions for low oxygen concentrations, which inhabit lowland areas. Therefore, the

hemoglobin of snow leopards is not adapted to high altitudes biochemically, and snow leopards rely on other adaptations like hyperventilation.

- **FALSE.** Increased P50 means that the hemoglobin has less affinity to oxygen. The graph shows a positive change in P50, which implies that KCl always lowers affinity. Therefore, KCl causes a stronger decrease in affinity to oxygen for the lion's HbA as opposed to the snow leopard's HbB (Figure 1C).

References:

Janecka JE, Nielsen SS, Andersen SD, Hoffmann FG, Weber RE, Anderson T, Storz JF, Fago A. Genetically based low oxygen affinities of felid hemoglobins: lack of biochemical adaptation to high-altitude hypoxia in the snow leopard. *J Exp Biol.* 2015 Aug;218(Pt 15):2402-9. doi: 10.1242/jeb.125369. PMID: 26246610; PMCID: PMC4528707.

Zubieta-Calleja G, Zubieta-Castillo G, Zubieta-Calleja L, Ardaya-Zubieta G, Paulev PE. Do over 200 million healthy altitude residents really suffer from chronic Acid-base disorders? *Indian J Clin Biochem.* 2011 Jan;26(1):62-5. doi: 10.1007/s12291-010-0088-9. Epub 2010 Nov 16. PMID: 22211016; PMCID: PMC3068777.

Task #40

- **TRUE.** From Figure 1, it can be observed that the light-fed mice were consistently less active than the dark-fed group over time. Light-fed mice also consumed slightly more calories than the dark-fed mice. The combined effect of a small increase in caloric intake and a small decrease in activity contributes to specific differences in body weight.
- **FALSE.** Mice are nocturnal animals with higher activity during the dark period (Figure 1) and less temperature fluctuation (Figure 2B). However, light-time feeding resulted in an increase in body weight and fluctuations in body temperature. Therefore, light-time feeding is an example of circadian-behavior misalignment.
- **FALSE.** The light-fed mice's body temperature range before the experiment was 36-38 and during the light-time feeding, it became 34-38

degrees Celsius (Figure 2A), while the dark-fed mice's body temperature range did not change (Figure 2B).

- **FALSE.** From Figure 1, it can be seen that with decreasing locomotor activity in light-fed mice, their caloric intake from the middle of week 2 to the middle of week 6 stays relatively the same.

Reference:

1. Damiola, F., Le Minh, N., Preitner, N., Kornmann, B., Fleury-Olela, F., & Schibler, U. (2000). Restricted feeding uncouples circadian oscillators in peripheral tissues from the central pacemaker in the suprachiasmatic nucleus. *Genes & development*, 14(23), 2950–2961. <https://doi.org/10.1101/gad.183500>

2. Arble, Deanna M et al. “Circadian timing of food intake contributes to weight gain.” *Obesity (Silver Spring, Md.)* vol. 17,11 (2009): 2100-2. doi:10.1038/oby.2009.264

Task #41

- **TRUE.** The rate of active bouts persisted through prolonged periods of constant light or darkness (Figure 1C), suggesting internal control or circadian rhythm.
- **FALSE.** From the figures it is seen that they are nocturnal animals because active and quiet sleep phases occur during the daytime.
- **FALSE.** There is no data provided that shows the changes in the average duration of active bouts after sleep deprivation.
- **TRUE.** There is an increased amount of bouts after sleep deprivation and there is a higher probability of bout being sooner if the bout is interrupted.

Reference:

Wake-like skin patterning and neural activity during octopus sleep. Aditi Pophale, Kazumichi Shimizu, Tomoyuki Mano, Teresa L. Iglesias, Kerry Martin, Makoto Hiroi, Keishu Asada, Paulette García Andaluz, Thi Thu Van Dinh, Leenoy Meshulam & Sam Reiter.

Task #42

- . **FALSE.** The electric eel employs low-voltage impulses to detect the presence of prey nearby. However, for direct localization of prey, it utilizes high-voltage impulses. This is evident from the eel's behavior of attacking the conducting rod, mistaking it for prey, as the rod affected the electric field generated by the high-voltage impulses.
- . **FALSE.** The eel initiated the attack on the rod because it detected the presence of prey nearby. It recognized this when the prey, in response to the low-voltage impulse, twitched, thereby creating a mechanical movement in the water, which the eel sensed.
- . **FALSE.** The frame indicates the time point when the high-voltage impulses commence (following the low-voltage one). From this, it can be inferred that the corpse has already twitched, and the eel has realized the presence of prey nearby.
- . **FALSE.** As stated in the explanation of the first point, for direct prey localization prior to attack, the electric eel employs high-voltage impulses. Mechanoreceptors only sense water vibrations after the prey twitches due to the low-voltage impulse.

Reference:

<https://www.nature.com/articles/ncomms9638#citeas>

Task #43

- . **FALSE.** Not all bones are represented by dark areas. For example, the eye sockets are shown in light gray.
- . **FALSE.** Conversely, as the passage widens, the airspeed decreases - Poiseuille's Law.
- . **FALSE.** Structure “l” is tongue (lingua), which has other primary functions
- . **FALSE.** Due to the large weight load per unit area of support, saigas more often fall into the snow, which makes them easier prey for wolves in winter

Reference:

1. Case studies in novel narial anatomy: 3. Structure and function of the nasal cavity of saiga (Artiodactyla: Bovidae: Saiga tatarica). Andrew B. Clifford and Lawrence M. Witmer.

https://people.ohio.edu/witmerl/Downloads/2004_Clifford&Witmer_saiga_nose.pdf

2. “Живые сокровища Казахстана” (“Living Treasures of Kazakhstan”) «Kazakhstan» Publishing House, Alma-Ata, 1979. Compiled by E. A. Bychkova. Scientific editors: E. V. Gvozdev, Academician of the Academy of Sciences of the Kazakh SSR; V. I. Kapitonov, Candidate of Biological Sciences.

Task #44

- **FALSE.** . Activation of TLR7/8 receptors on X-chromosome bearing sperm cells decrease their progressive motility (See Graph A of Figure 2).
- **TRUE.** . See Graph C of figure 2. High-mobility sperm cells that don't have TLR7/TLR8 receptors (and more likely to have Y chromosome) are in the upper layer.
- **TRUE.** . Results shown in graphs B and C of Figure 2 allow us to conclude that this is a viable method of sorting sperm cells by sex.
- **TRUE.** . Difference between R and C groups under different glucose concentration from Graph A of Figure 2

References:

Umehara, T., Tsujita, N., Zhu, Z., Ikeda, M., & Shimada, M. (2020). A simple sperm-sexing method that activates TLR7/8 on X sperm for the efficient production of sexed mouse or cattle embryos. Nature protocols, 15(8), 2645–2667. <https://doi.org/10.1038/s41596-020-0348-y>

Umehara, T., Tsujita, N., & Shimada, M. (2019). Activation of Toll-like receptor 7/8 encoded by the X chromosome alters sperm motility and provides a novel simple technology for sexing sperm. PLoS biology, 17(8), e3000398. <https://doi.org/10.1371/journal.pbio.3000398>

Task #45

- . **TRUE.** . Cross - sections of samples with EC(+) shows luminal structures and better media supply, which shows that EC increases the formation of new vessels, while function of FGF2 is to promote communication with the vascular bed.
- . **FALSE.** . As you can see in the figures H and G with green fluorescence, the green dots are not actively distributed in the cell sheet area in image G, while at image H, EC are actively distributed around the cs.
- . **TRUE.** . By assuming that cells have the same proliferation rate (from the same culture of cells), the plateau state in the bioluminescence rate indicates the cell survival rate, because at the plateau point, the number of living cells with luciferase enzyme is the only limiting factor. It is true that EC(-) FGF(+) has higher cell survival than EC(+) FGF(-).
- . **FALSE.** . For EC(+) FGF(+) the rate can not mainly be explained by simple direct diffusion, because direct diffusion alone can not be that fast as you can see in the example of all EC(-) samples. The combined effect of direct diffusion and transport by newly developed vessels provides a fast increasing state.

References:

- In vitro fabrication of functional three-dimensional tissues with perfusable blood vessels

<https://www.nature.com/articles/ncomms2406>

Task #46

- . **FALSE.** We can see that neurons can fire action potential with higher frequency (Figure 1C) meaning that this pattern is formed due to different reasons.
- . **FALSE.** Since the membrane potential rises for the fourth time, the neuron is not in the absolute refractory period, therefore, with an increase in the signal duration, more ions will enter the cell and the potential may reach the threshold value.

- . **TRUE.** The potential of sodium is much further from its equilibrium potential than the potential of potassium, therefore, even with the free movement of both cations, more sodium will enter the cell.
- . **TRUE.** For the generation of action potential any duration of light pulse longer than certain threshold can work, however to get subthreshold depolarization duration of light pulse should be more precise.

Reference:

Boyden, E., Zhang, F., Bamberg, E. et al. Millisecond-timescale, genetically targeted optical control of neural activity. Nat Neurosci 8, 1263–1268 (2005). <https://doi.org/10.1038/nn1525>

Task #47

- . **FALSE.** Flying animals require more energy for the beginning of the movement.
- . **FALSE.** It is possible to find the lowest value by solving an equation or taking the derivative. $V = 0.79 \text{ km/h}$.
- . **FALSE.** Since each type of gait has its minimum, animals would switch between these COT minimums without moving on the intermediate speeds - multimodal distribution (with 3 peaks).
- . **TRUE.** Cod experiences increasing drag because of the movement in the water, running animals experience negligible air drag.

References:

Moyes, C. D., & Schulte, P. M. (2016). In Principles of Animal Physiology (pp. 535–538). essay, Pearson.

Task #48

- . **TRUE.** The person does full expiration and the only remaining volume is RV, meaning that the spirometer is now $V_s + ERV$
- . **FALSE.** From the description of the process, it is possible to notice that we form a closed system when a person starts to breathe in a spirometer.

It means that the amount of helium at the beginning of the experiment should be equal to the final amount: $C_1V_s = C_2(V_{sf} + RV)$. As a result, we can calculate $RV = (C_1V_s)/C_2 - V_{sf}$. $RV_1 = (10 \times 5)/8 - 5.6 = 0.65L = 650 \text{ ml}$

- . **TRUE.** Constant inspiratory volume + increased RV = increased lung volume.
- . **TRUE.** Patient 2 has decreased RV and decreased ERV, meaning that its total lung volume is also smaller with less RV left inside, pneumothorax can explain this as the patient would only have one functioning lung.

Reference:

Moyes, C. D., & Schulte, P. M. (2016). In Principles of Animal Physiology (pp. 574–575). essay, Pearson.

Task #49

- . **TRUE.** Tachycardia is increased heart rate, meaning that the time between each heartbeat, and consequently systole, is smaller.
- . **FALSE.** High arterial pressure means that there is higher pressure in the aorta during the systolic phase and more resistance to ventricular contraction. Higher resistance results in lower peak velocity.
- . **TRUE.** . By simply rearranging the equation, we get that $v = c(\Delta f)/(2 \times f_0 \times \cos(\theta)) = 120 \text{ cm/s}$
- . **TRUE.** The area under the curve represents the distance traveled by the blood during the entire systole. Blood travel distance = $0.33 \times 100 / 2 = 16.67 \text{ cm}$. We know the distance and we know that the aorta has a radius of 1.25 cm, meaning that the volume traveled through the aorta is $16.67 \times (\pi \times 1.25^2) = 81.8 \text{ cm}^3$. From the graph, it is also seen that the heart rate is 60 bpm, $CO = 81.8 \times 60 = 4908 \text{ cm}^3 = 4.9 \text{ L}$.

References

<https://www.deltamedical.com/downloads/TechnicalReview.pdf>

Task #50

- . **FALSE.** While hydrostatic pressure drives blood through the glomerulus, water moves via secondary active transport after the sodium.
- . **TRUE.** While at the same depth, 1 and 3 have different osmolarities, this is not due to the water movement, but rather because of the reabsorption of the sodium in the collecting duct.
- . **FALSE.** Osmolarity should be higher than 290 so that water would establish 290 in the descending limb, as well as in the collecting duct.
- . **TRUE.** In this case, sodium will be left in the kidney and gradually all of the sodium will accumulate in the medulla.

Reference:

WINTERS, R. W., & DAVIES, R. E. (1961). The role of countercurrent mechanisms in urine concentration: a review. *Annals of Internal Medicine*, 54(4), 810-826