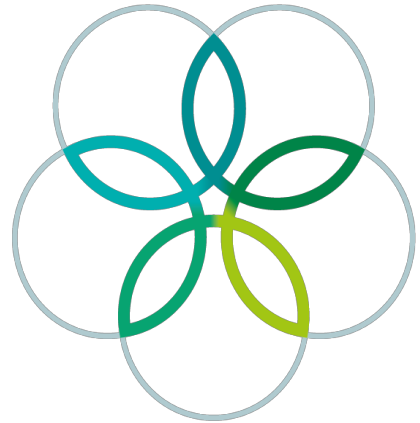
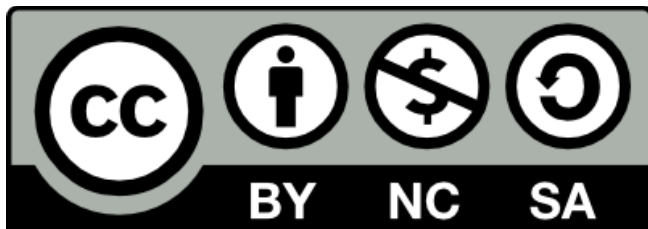


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Theoretical Exam - Part B



G0-1

English (Official)

General Instructions for Theory Part B

Date: July 11th, 2024

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

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

- **Biosystematics:** Q1-2
- **Cell and Molecular Biology:** Q3-13
- **Ecology:** Q14-18
- **Ethology:** Q19-21
- **Genetics & Evolution:** Q22-31
- **Plant Anatomy and Physiology:** Q32-38
- **Animal Anatomy and Physiology:** Q39-50

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 "IDN₂" 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 "IDN₂" and "Answers" fields are completely shaded with no unshaded areas remaining and without going outside the boundaries. Marks like "+", "x", check-

Theoretical Exam - Part B



G0-2

English (Official)

marks, or circles will not be read. Black squares must be shaded with a black pen (using a red pen or pencil is strictly prohibited).

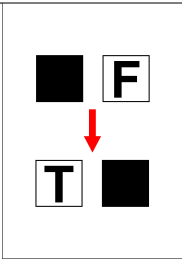
Do NOT fill out the "charge person" field and do NOT shade any fields that are not specified above. Black squares in the corners SHOULD NOT be shaded/corrected as it will interfere with the scanning process.

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.

Biosystematics

1

Dichotomous keys are essential tools in taxonomy. They consist of a series of statements, each highlighting a distinct morphological characteristic that may be true or false depending on the organism under observation. As the organism is compared with these statements, the key systematically directs the user through a decision tree, ultimately leading to a specific taxonomic classification (Figure 1).

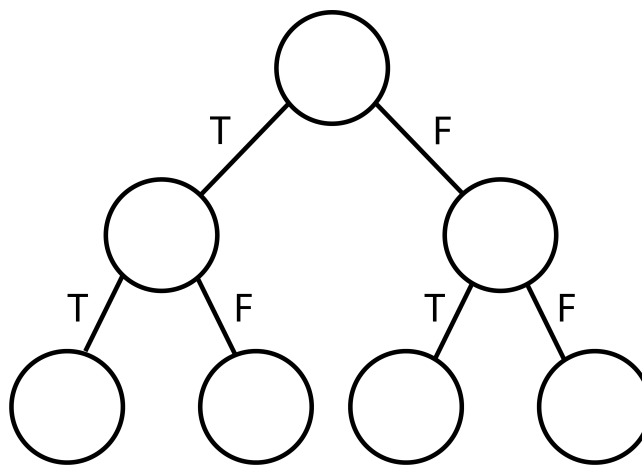


Figure 1. Dichotomous tree model with three levels; T - true, F - false.

To determine the species of an unknown organism, referred to as X, you utilize a hypothetical dichotomous key with 10 levels, structurally similar to the one depicted in Figure 1. The final level of this tree provides a conclusive taxonomic identification, with no further branching points. The tree has a complete set of nodes without terminating branches before the final level.

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

- A.** Determining the species of an organism with more complex morphological structures than that of organism X using the provided key will take more than 9 steps.
- B.** The maximal number of species that could be identified with the key is 512.
- C.** An identification step at level 3 (counting from the top) has four times more possible final taxonomic outcomes than an identification step at level 5.
- D.** Consider three taxa A, B, and C. If A and B share a more recent common ancestor than A and C, then the paths along the dichotomous key leading to A and B will certainly diverge at an earlier step than the paths leading to A and C.

2

There are many subspecies of Red Deer (*Cervus elaphus*) in Eurasia (figure 1).



Figure 1. Red Deer in the National Park "Kölsay kölderi"

The cytochrome b gene of mitochondrial DNA from 106 red deer samples, collected from different localities and representing different subspecies, was analyzed.

Figure 2 shows part of the phylogenetic tree of *Cervus* samples based on the analysis of the mitochondrial DNA cytochrome b gene.

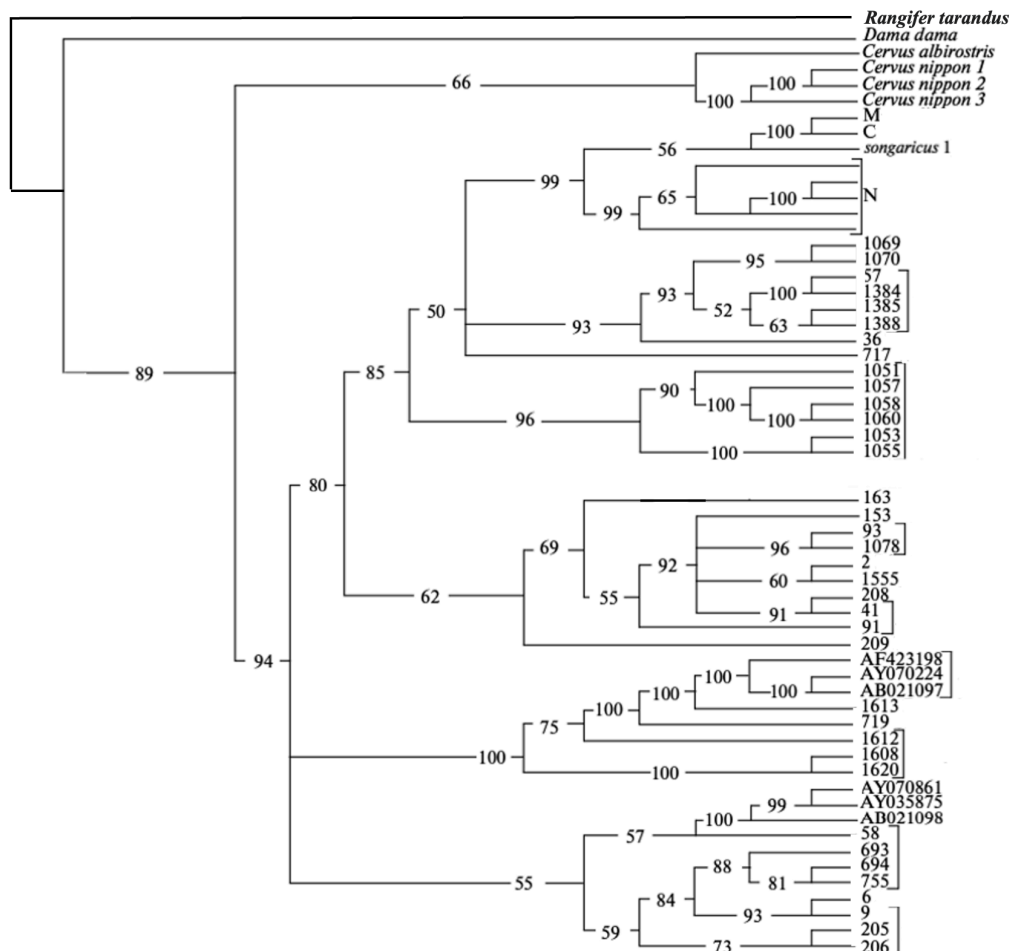


Figure 2. Phylogenetic tree of Red Deer. The numbers on each branch are called bootstrap values. They indicate how many times out of 100 iterations the same branch is observed when repeating the generation of a phylogenetic tree on a resampled set of data. (all the tips with numbers or letters indicate various groups of *Cervus elaphus*)

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

A. In 11 out of 100 bootstrap iterations *Dama dama* was not a sister group to *Cervus spp.*

B. Using the DNA of histone genes instead of mitochondrial DNA for construction of this phylogenetic tree would allow to better differentiate between deer subspecies.

C. Sample 163 is part of the most weakly supported branch in the tree.

D. A bootstrap value of 50 indicates the existence of only one alternative topology.

Cell and molecular biology

3

DNA double-strand breaks (DSBs) occur when both strands of the DNA molecule are broken, leading to cell death if not properly repaired. DSBs occur frequently and are primarily repaired through homologous recombination (HR) or non-homologous end-joining (NHEJ). As shown in Figure 1, the BRCA1 protein, when activated by DSBs, inhibits the 53BP1 protein, promoting the HR pathway. Alternatively, 53BP1 can be recruited to DSB sites, where it promotes the NHEJ pathway. Activation of either HR or NHEJ can be sufficient for cell survival. Figure 2 shows the level of BRCA1 protein and cell cycle profile of normal cells. 53BP1-deficient cells have similar BRCA1 protein and cell cycle profile as normal cells. 53BP1 protein level remains relatively same throughout the cell cycle in both normal and BRCA1 deficient cells. BRCA1 is required for the activation of HR pathway regardless of the presence of 53BP1.

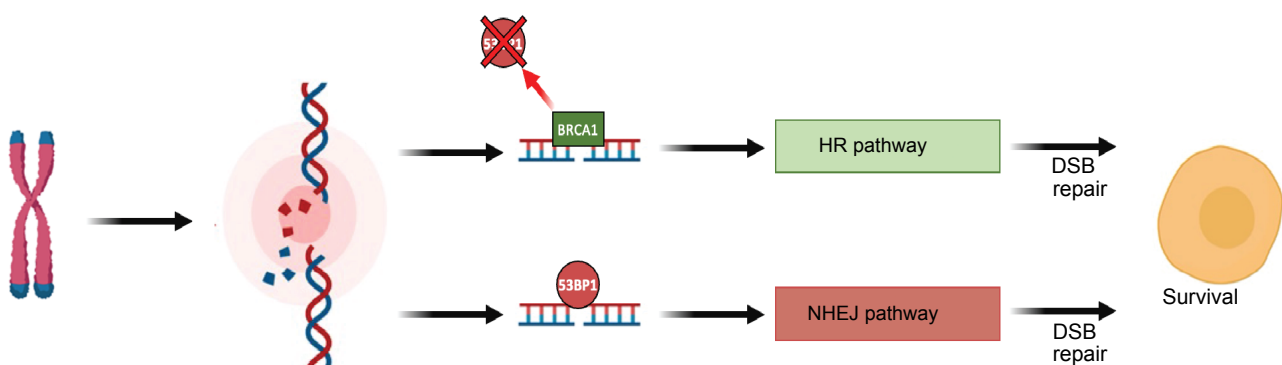


Figure 1. DSB repair pathways in normal cells. The red arrow indicates inhibition.

Theoretical Exam - Part B



Q2-2

English (Official)

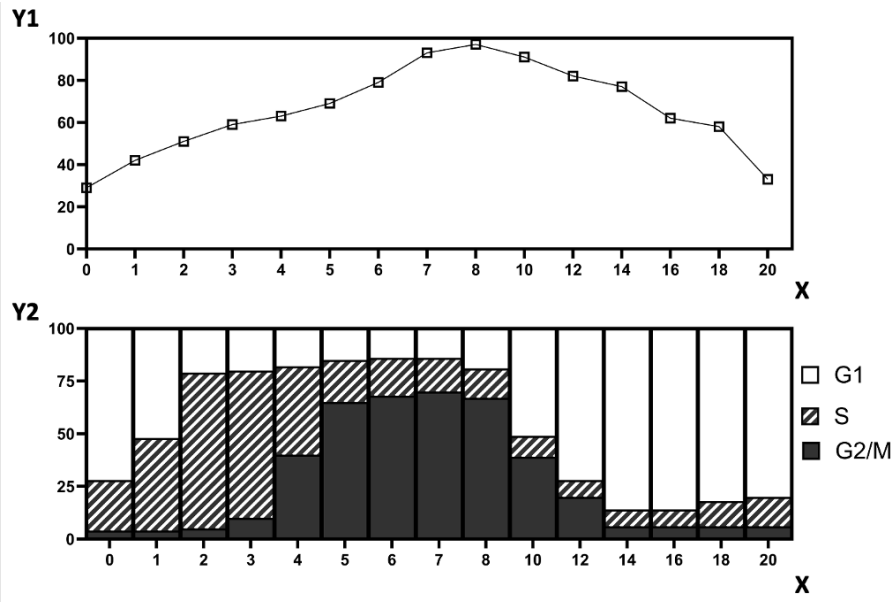


Figure 2. Normal cells were sampled over 20 hours and BRCA1 protein concentration relative to the maximum and the proportions of cells in various stages of cell cycle are analyzed. **Y1** = BRCA1 protein (%). **Y2** = % of Cells. **X** = Hours.

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

- A.** The DSB repair pathway choice correlates with cell cycle status.
- B.** BRCA1-deficient cancer cells exhibit an increased reliance on the NHEJ pathway for DNA repair.
- C.** In normal cells, the HR pathway is more active in the G1 phase compared to the G2 phase.
- D.** Inhibitors of the transition from the G1 to the S phase will be more detrimental to 53BP1-deficient cells compared to BRCA1-deficient cells.

Theoretical Exam - Part B



Q2-3

English (Official)

4

A scientist in a lab is investigating two types of calcium channels in pancreatic beta cells. When Channel A opens, it allows an influx of calcium ions (Ca^{2+}) into the cytosol. This rise in cytosolic Ca^{2+} triggers further calcium release from the endoplasmic reticulum (ER) via ryanodine and inositol trisphosphate receptors, and can activate Channel B to sustain the calcium signal. Mitochondria help modulate this calcium signaling by buffering excess Ca^{2+} , which influences both energy production and cellular responses.

In mitochondria, calcium activates Krebs cycle enzymes (isocitrate dehydrogenase, alpha-ketoglutarate dehydrogenase), enhancing ATP production. Also, in these cells, calcium release triggers insulin release in response to high glucose levels.

Mitochondrial calcium in pancreatic beta cells was measured using a fluorescence microscope with a calcium sensor. Inhibitors used: Inhibitor X (Channel B blocker) and Inhibitor Y (Channel A blocker). Results are shown in the graph below:

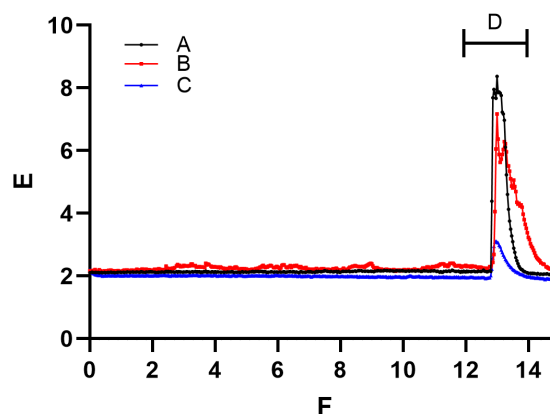


Figure 1. Calcium concentration under different conditions. A - control, B - inhibitor X, C - inhibitor Y, D - 30mM K^+ , E - calcium concentration (a.u.), F - time (mins). (cell media before D is applied: 2mM Ca^{2+} , 5mM K^+ , low glucose)

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

A. In figure 1, cells depolarize after addition of 30mM K^+ .

B. From the experiment data provided we can conclude that the Channel A is ligand-gated.

C. If we performed a new experiment and replaced 30 mM K^+ with high glucose in control conditions, the calcium concentration would not increase after high glucose stimulation.

D. If the same experiment as in Figure 1 was conducted in 0mM Ca^{2+} media, the response of the control cells would show a similar response to the inhibitor Y graph in Figure 1.

5

Ketogenic (high-fat, low-carbohydrate) diet is an efficient treatment for recurrent seizures, as in epilepsy. Ketogenic diet is thought to exert its effect via a metabolic pathway shown in Figure 1, as it leads to a production of beta-hydroxybutyrate. Increasing the number of reactions in a biochemical pathway decreases its overall reaction rate.

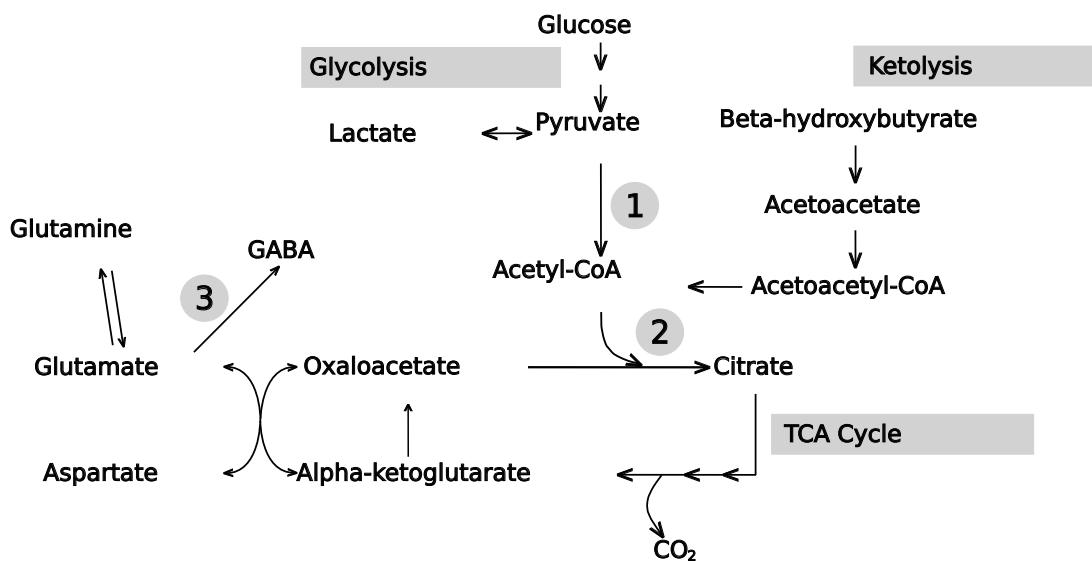


Figure 1.

Dopamine is known to play a role in muscle control (e.g., its deficiency is one of the causes of Parkinson's disease). A study investigated the interaction of catecholamines (dopamine, noradrenaline, and adrenaline, refer to Figure 2A) with a ketogenic diet. The study used *Dbh* (Figure 2A) knockout (*Dbh*^{-/-}) and heterozygote (*Dbh*^{+/-}) mice that were fed with either a ketogenic or normal diet. To estimate the efficacy of the diet in each group, they were introduced to fluorothyl (a seizure-inducing agent), and the latency to the first seizure was measured (Fig. 2B).

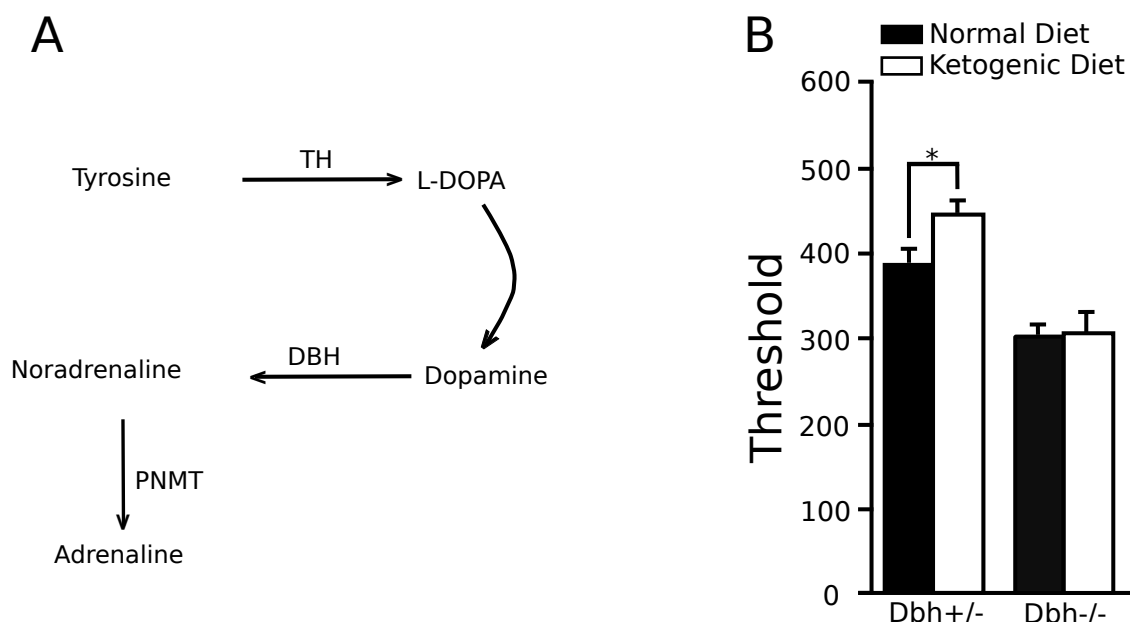


Figure 2. **A** Metabolism of catecholamines. **B** Seizure latency threshold (in milliseconds) after provocation with fluorothyl in *Dbh* +/- and -/- mice fed either the standard or ketogenic diet. Asterisk indicates a significant difference.

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

- A.** A ketogenic diet facilitates the conversion of alpha-ketoglutarate to glutamate.
- B.** A mutation reducing the K_m of the enzyme that catalyzes reaction 2 in Figure 1 decreases the value of the seizure latency (in milliseconds) in (*Dbh* +/-) mice with a ketogenic diet.
- C.** L-DOPA can be used as both an anti-convulsant and a treatment for Parkinson's disease.
- D.** The study is certainly conclusive that noradrenaline enhances GABA's anti-seizure functions.

6

ProQC is a synthetic biology tool used for the quality control of protein expression. ProQC consists of a synthetic gene-expression complex that only allows the expression of gene of interest (GOI)-encoded protein only from the full-length mRNAs. It is composed of two parts: a toehold switch containing a ribosome binding site (RBS) at the 5' end of the GOI, and a cis-trigger at the 3' end of the GOI (Figure 1), both under the same promoter. The sequence of the cis-trigger is reverse complementary to the toehold switch. When the toehold switch portion of the synthetic cassette is free, it forms a hairpin-like structure that blocks the RBS sequence.

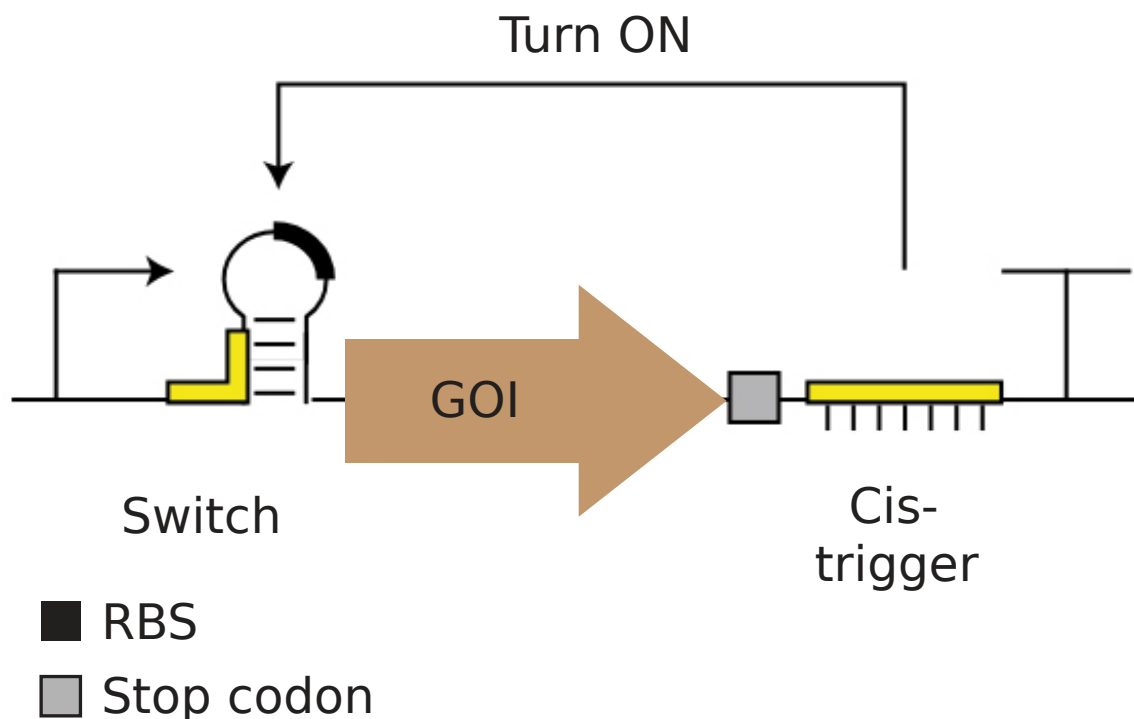


Figure 1. Schematic diagram of one of the possible conformations of the ProQC system.

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

- A.** The ProQC system allows translation only when the cis-trigger binds to the toehold switch.
- B.** The ProQC system increases the yield of functional proteins and reduces the waste of cellular resources.
- C.** This system is not necessary in eukaryotic cells.
- D.** In the ProQC system, the RBS in the toehold switch can be unblocked by trigger RNA transcribed separately from the ProQC system.

7

DNA fiber assay is used to study various aspects of DNA synthesis, such as replication speed, replication origin firing, and replication termination. It utilizes modified nucleotides to visualize the progression of DNA replication directly. In this assay, cellular DNA is sequentially labeled with chloro-deoxyuridine (CldU) followed by iodo-deoxyuridine (IdU), each for an equal period. Upon replication, cells incorporate these modified nucleotides into newly synthesized DNA. Next, cells are lysed and individual DNA fibers are stretched on a microscopic slide, followed by CldU (red) and IdU (blue) antibody staining. Finally, DNA fibers are visualized by fluorescent microscopy.

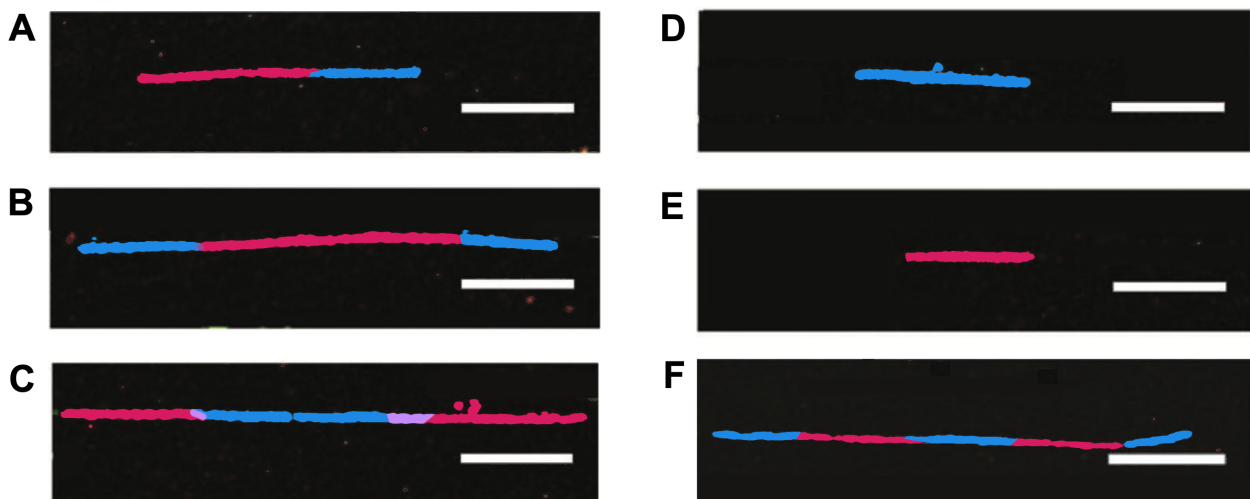


Figure 1. Panels A-F represent replicated DNA segments. Each panel shows a single uninterrupted DNA molecule labeled with CldU (red) followed by IdU (blue). The white bar at the bottom right of each panel is a scale bar of 10 μ m. The DNA in all panels is from the same organism.

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

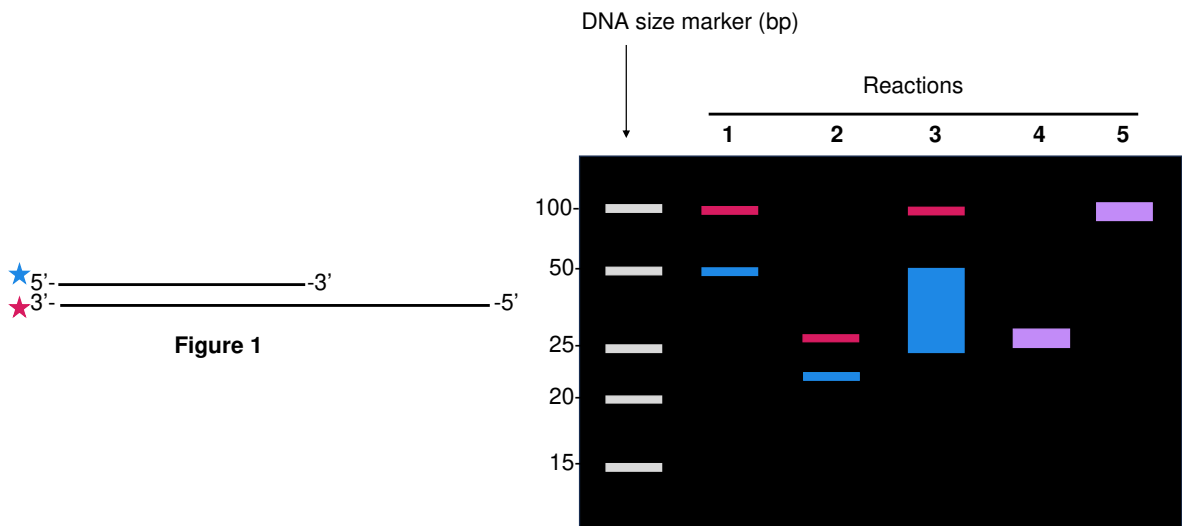
- A.** Panel A can represent replication progression from a single replication fork, while panel B shows replication progression from two forks.
- B.** Both panels C and E demonstrate replication termination.
- C.** In panel B, CldU is incorporated into either a leading or lagging strand of DNA but not into both.
- D.** The DNA belongs to a bacterial species.



8

An in vitro experiment with enzymes involved in DNA metabolism was performed using the double-stranded DNA substrate shown in **Figure 1**. The upper strand of the DNA substrate is 50 bases, and the 5' is labeled with blue fluorescent dye, while the lower strand is 100 bases, and the 3' is labeled with red fluorescent dye. Fluorophore-labeled ends are chemically inert.

The reaction scheme is shown in **Table 1**. After each reaction, DNAs were separated using denaturing polyacrylamide gel electrophoresis to separate denatured single-stranded DNAs (**Figure 2**, the purple color indicates the presence of both DNA strands at the same position)



Reaction number	Reaction scheme
1	DNA substrate alone
2	Reaction with the enzyme A
3	Reaction with the enzyme B
4	Reaction with the enzyme A Inactivation of the enzyme A Addition of enzyme C
5	Reaction with the enzyme B Inactivation of the enzyme B Addition of enzyme C

Table 1. Reaction scheme



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

- A.** Enzyme A is an endonuclease, generating blunt-ended breaks.
- B.** Enzyme B is an exonuclease with a 3'-5' polarity.
- C.** Enzyme C is a DNA polymerase.
- D.** If an additional reaction were performed with enzyme C alone, the result would be the same as the result of reaction 4.

9

Researchers studied the effect of compound X on the cell cycle progression of diploid human cells and how checkpoint kinases A and B regulate cellular response to this compound.

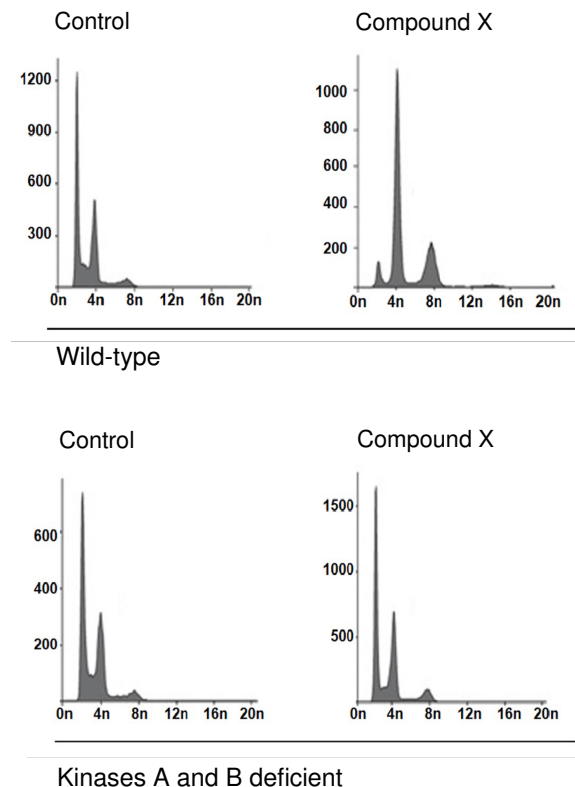


Figure 1. Results showing how the DNA amount in a dividing cell is affected under indicated conditions (Horizontal X-axis: DNA amount, where 2n represents the DNA content in a non-dividing diploid normal cell. Vertical Y-axis: Cell number).

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

- A.** Based on the results, under normal conditions (wild-type, control), cells are mainly in the G2 phase of the cell cycle.
- B.** Compound X induces polyploidy.
- C.** The effect caused by compound X is independent of protein kinases A and B.
- D.** Upon treatment with Compound X, protein kinases A and B prevent several rounds of DNA replication within one cell division.

10

Proteins A and B form a heterodimer and only then do they induce stem cell differentiation. Protein A is regulated at the transcriptional level by transcription factor X, which is in turn regulated by the ligand L. On the other hand, protein B is regulated post-translationally through phosphorylation and dephosphorylation at serine-121 residue.

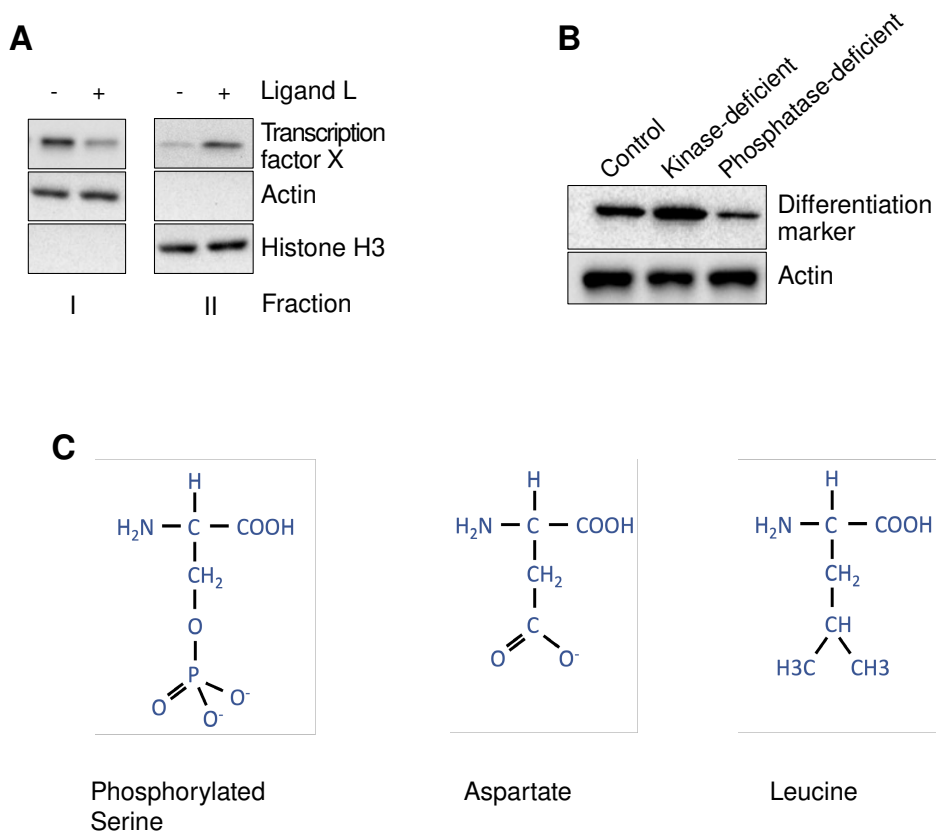


Figure 1. **A** Researchers isolated DNA-bound and unbound proteins (fractions) and analyzed the abundance of transcription factor X by Western Blot analysis but forgot to label the fractions. **B** Researchers studied how the deficiency of kinase and phosphatase affects the differentiation of cells by performing a Western Blot analysis. The higher the differentiation marker the higher the chance of differentiation. **C** The structures of phosphorylated serine and two other amino acids. Note that one amino acid can mimic phosphorylated serine.



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

- A.** For quick cellular response, the regulation mechanism of protein B's activity is more energy-efficient than that of protein A's.
- B.** Ligand L reduces the affinity of transcription factor X to DNA.
- C.** Phosphorylation of protein B prevents the interaction of proteins A and B.
- D.** Mutating the serine-121 residue in protein B to aspartate likely causes the same effect on the formation of heterodimers as the activity of the kinase.

Theoretical Exam - Part B



Q2-13

English (Official)

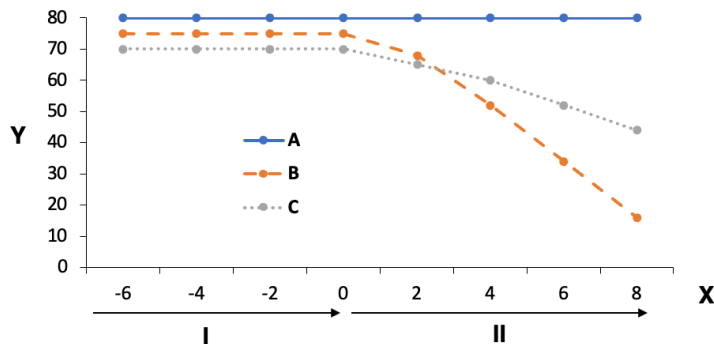
11

Proteasomes, cytoplasmic multiprotein complexes, and lysosomes are major proteolysis (protein degradation) sites in eukaryotic cells.

In Figure 1-a, researchers studied the abundance of proteins A, B, and C over time in cultured human cells using cycloheximide, an inhibitor of translation elongation in eukaryotic 80S ribosomes. Note that cycloheximide does not affect the abundance of protein A, whose half-life is shorter than that of protein B.

In Figure 1-b, they observed how MG132, a proteasome inhibitor, and chloroquine, a lysosome inhibitor, affect the abundance of proteins B and C over time under cycloheximide treatment.

1-a



1-b

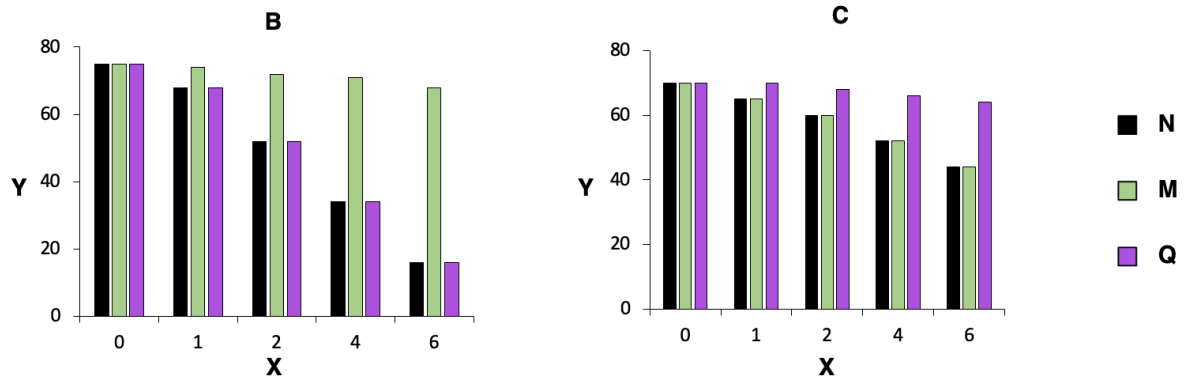


Figure 1. **1-a** Y: Protein abundance, X: Time (hours), I: Before adding cycloheximide, II: After adding cycloheximide, A: protein A, B: protein B, C: protein C. **1-b** Y: Protein abundance, X: Time after adding cycloheximide (hours), B: protein B, C: protein C, N: control, M: MG132, Q: Chloroquine.



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

- A. Cycloheximide treatment alone provides direct information on the rate of protein synthesis.
- B. The half-life of protein B is shorter than the half-life of protein C.
- C. Protein A is more likely to be mitochondrial than proteins B and C.
- D. Protein B is more likely to be an extracellular protein than protein C.

12

Förster Resonance Energy Transfer (FRET) is a technique used to study the interaction between two chromophores, donor and acceptor. The donor (D) can be excited by light of a specific wavelength, raising the energy of an electron in the molecule. When far away from the acceptor (A), it will emit light via fluorescence. However, when it is within 10 nm of an acceptor molecule, it can "transfer" its energy to the acceptor, which then releases the absorbed energy as a different wavelength of light (compare **Figures 1a and 1b**).

For an efficient FRET, the emission spectra of the donor must overlap with the excitation spectra of the acceptor. **Table 1** lists some chromophores' excitation and emission spectra, including CFP and YFP.

Researchers used FRET to find the optimal protease (**Figure 2**). Here, CFP and YFP fluorescent proteins are linked (CFP-YFP) with the protease-target peptide sequence. Researchers also observed the effect of two inhibitors on Protease P3 by using FRET (**Figure 3**). Note that one inhibitor is competitive, while the other is non-competitive.

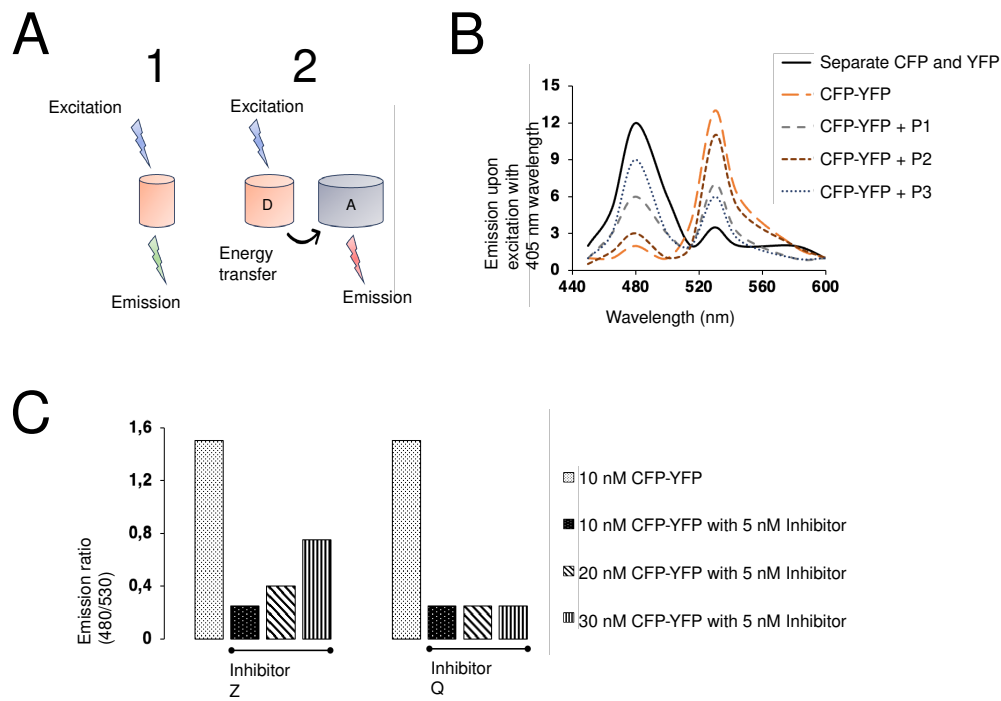


Figure 1. **A** Scheme of regular fluorescence (1) and FRET (2). **B** Emission spectrum upon excitation of 5 samples. **C** Effect of two inhibitors on the activity of Protease P3 measured by FRET.

Fluorophore	Excitation range (nm)	Emission range (nm)
TQ7	480-540	580-635
Brim43	510-570	600-660
G8	590-650	670-710
CFP	390-450	460-510
YFP	480-530	515-560

Table 1. Excitation and emission spectra of some fluorophores.



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

- A.** The probability of FRET decreases if the concentration of both donor and acceptor in the same solution is increased.
- B.** Using Brim43 as the acceptor, the most optimal donor is G8.
- C.** Protease P3 has the highest activity among tested proteases.
- D.** Z and Q are competitive and non-competitive inhibitors, respectively.

13

Telomeres are critical structures at the end of eukaryotic chromosomes, preventing the loss of genetic information during cellular divisions. Since telomeres resemble DNA breakpoints (**Figure 1A**), they need to be protected from cellular DNA break repair mechanisms to prevent the ligation of the telomeric ends of different chromosomes. For that, a protein complex, shelterin, generates a structure shown in **Figure 1B**.

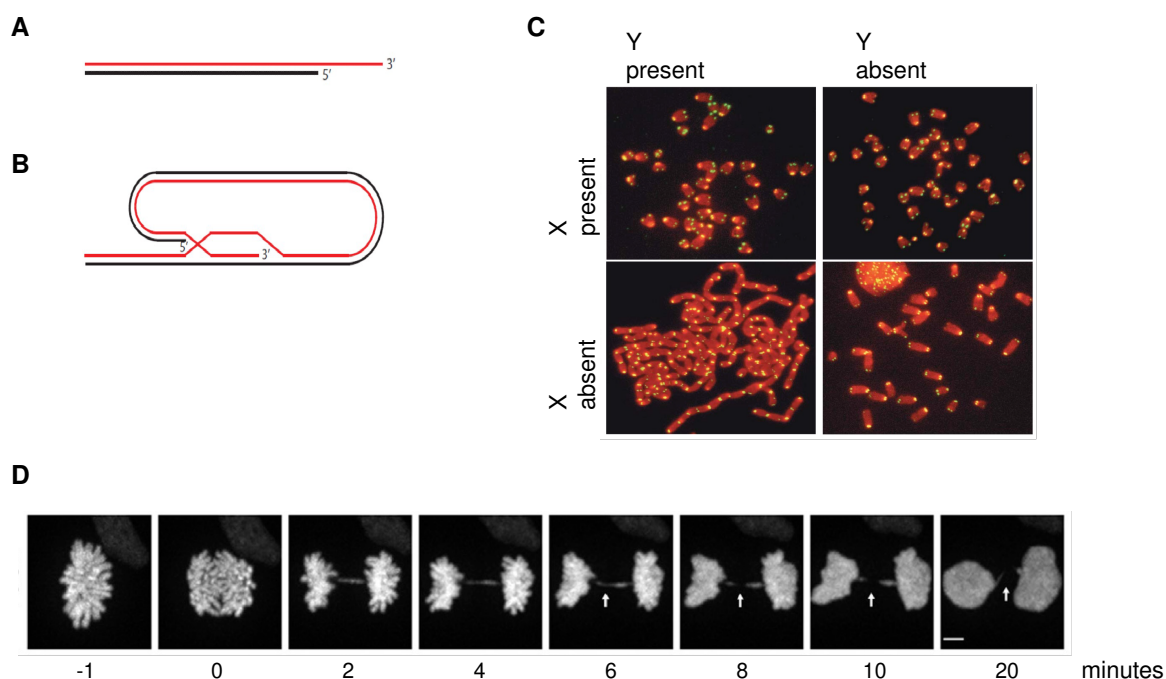


Figure 1. **A, B** Refer to the question text. **C** Microscopic images showing how factors X and Y affect the structure of chromosomes (one of the factors is a subunit of the shelterin complex) Telomeres are labeled with the green probe. **D** Microscopic images showing how unprotected telomeres result in chromosomal bridges during mitosis (white arrows point to the chromosome breakage, which starts at 6 min).

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

A. The structure shown in **Figure 1B** also protects telomeres from nucleases resolving meiotic recombination.

B. Factor Y is more likely to be involved in DNA break repair than factor X.

C. The bridged chromosome in **Figure 1D** has at least two centromeres.

D. The force generated by the kinetochore-associated microtubules physically breaks the bridged chromosome.

Ecology

14

The Aral Sea, located in the southwest of Kazakhstan, was one of the largest salt lakes in the world before drying out. Today, the Aral Sea has two basins: Northern and Southern. Freshwater rivers: Syr Darya flows into the Northern basin and Amu Darya flows into the Southern basin. The water from Amu Darya is overused in agriculture, thus only a small part flows into the sea.

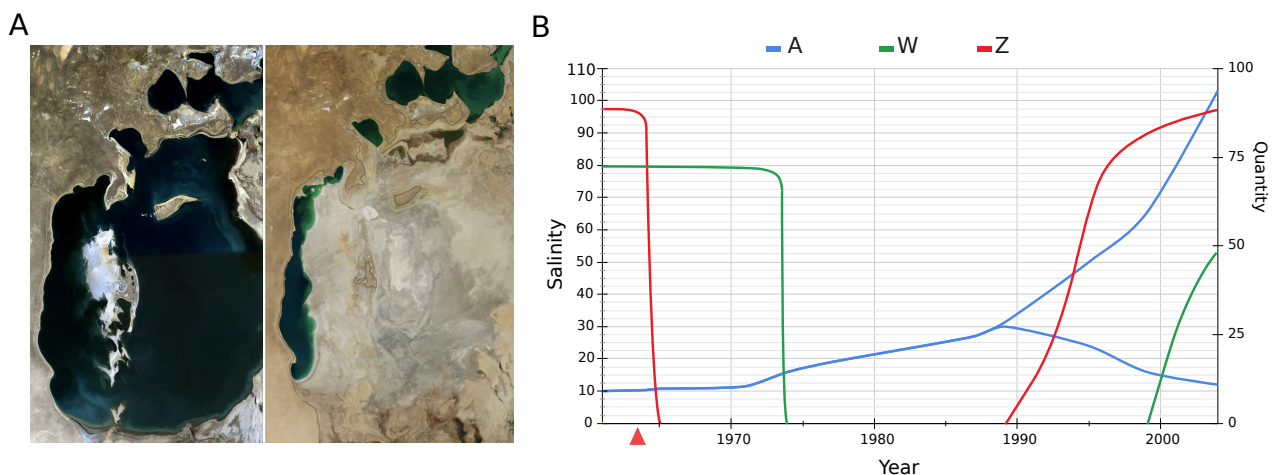


Figure 1. **A** The Aral Sea before and after. **B** Graph of changes in the salinity of both basins (mg/mL) and quantity metric of adult organisms (arbitrary units). A – salinity, W – species W, Z – species Z. The red arrow indicates the artificial introduction of a community of new species.

One way of restoring the biota of the Aral Sea is by introducing a food chain of new organisms into the sea. In Figure 1B, you can see a graph of changes in water salinity and the quantity of adult individuals of two unrelated species of animals living in the Aral Sea. Note that species W and Z are native to the Aral Sea ecosystem, and also inhabit freshwater rivers flowing into the Aral Sea.

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

A. A fish species introduced for biota restoration must feed on phytoplankton.

B. Species Z is more resistant to high salt concentrations than species W.

C. It's more likely that the return of species W happened earlier in the Northern Aral than in the Southern.

D. Among the artificially introduced animals, there were organisms that are prey for species Z but not predators of species Z.

15

The Lotka-Volterra model is used to predict the dynamics of competing populations. It is based on the following equations and is analyzed by constructing specific lines (Figure 1A).

$$\frac{dN_1}{dt} = r_1 N_1 \left(\frac{K_1 - N_1 - \alpha N_2}{K_1} \right), \quad \frac{dN_2}{dt} = r_2 N_2 \left(\frac{K_2 - N_2 - \beta N_1}{K_2} \right)$$

where, K - carrying capacity, N - number of individuals, r - intrinsic rate of increase, α - competition coefficient of species 2 on species 1, β - competition coefficient of species 1 on species 2, and dN/dt = population growth rate.

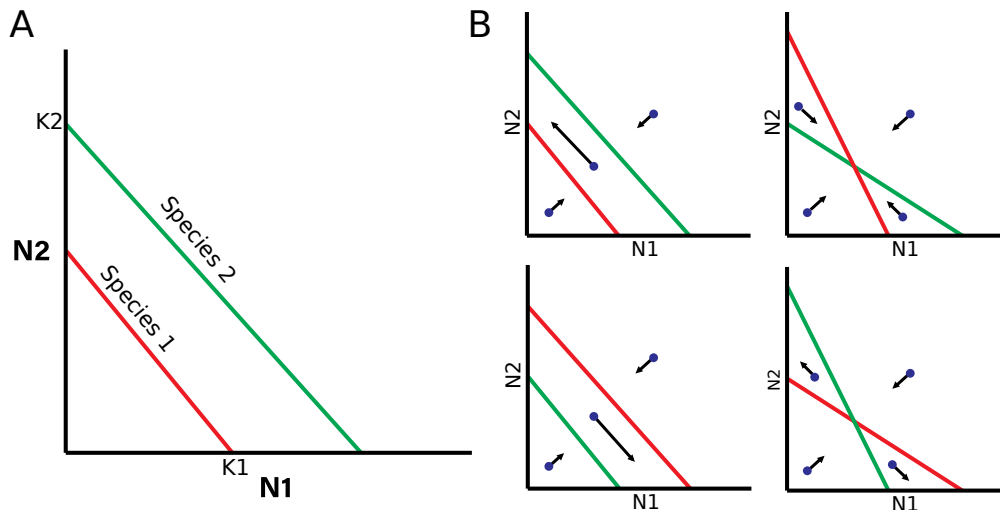


Figure 1. **A** Lotka-Volterra lines. **B** Combinations of line locations and trends.

The Lotka-Volterra line represents the number of individuals in a population at equilibrium ($dN/dt = 0$). For two species in competition, there are only 4 combinations of the location of these lines.

Depending on the initial values of populations, the future changes in populations' dynamics can be predicted. In Figure 1B you can see arrows that show the further direction of populations' dynamics for particular initial values that are indicated by blue dots.



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

- A.** The y-intercept for line of species 1 is equal to K_1/α .
- B.** This model takes into account the presence of intraspecific competition.
- C.** Suppose that there is a certain community of elks ($K_1 = 200$, $\alpha = 1$) and deer ($K_2 = 100$, $\beta = 2$) competing with each other. If the current populations are 120 elks and 60 deer, the elks will eventually outcompete the deer.
- D.** In only 2 scenarios out of 4 described in Figure 1B both species can stably coexist

16

The “hypothesis of intra-niche dimensions” states that stable coexistence in one ecological niche can be reached if the growth of one species is constricted by one limiting factor and the growth of a neighbour species by another. The balance of limiting factors creates trade-offs, allowing more than one species to occupy different “dimensions” within a niche; otherwise, a more adapted species will completely displace a less adapted one.

In the steppe conditions, *Stipa capillata* is more resistant to drought compared to other perennial grasses. However, since its root system is weak, it cannot spread vigorously in grasslands with good perennial turf.

Turf is a surface layer of soil, densely overgrown with short herbaceous plants very close to the ground.



Figure 1. *Stipa capillata*

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

A. Based on the hypothesis, fast-growing plants usually overpopulate nutrient-poor soils.

B. Horses grazing in the meadows of *Stipa* grass can help increase the number of other plant species in the steppe.

C. Uncontrolled ploughing of steppe areas will lead to a decline in the biomass of *Stipa* grass relative to other perennial grasses.

D. During the drought season, the biomass of turf may decrease, particularly, owing to the reduced photosynthesis in turf.

17

The incompatible insect technique (IIT) controls harmful insects by inducing mating incompatibility with the use of *Wolbachia* bacteria. *Wolbachia* kills embryos only when an infected sperm fertilizes an uninfected egg, while other combinations show no developmental issues. *Aedes albopictus* is a mosquito species with males as active gamete dispersers. A study on IIT effectiveness began with collecting *Wolbachia*-free fertilized eggs from the wild. After being reared in the lab, newly hatched mosquitoes were irradiated to sterilize only females. All mosquitoes were then infected with *Wolbachia* and released into experimental sites, while control sites received wild-type mosquitoes. Hatched eggs were counted, with their spatial distribution shown in Figure 1.

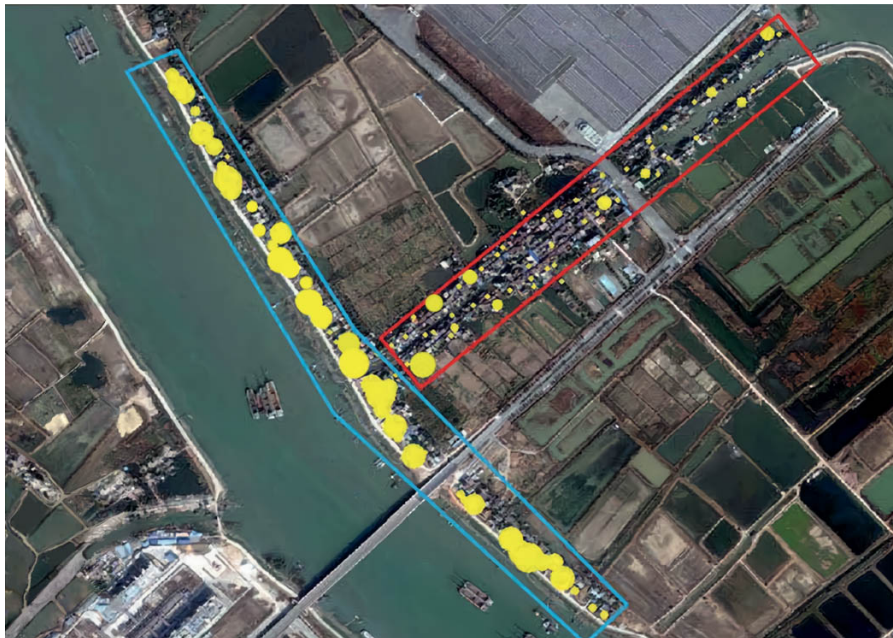


Figure 1. Spatial distribution of hatched eggs. The red polygon marks the experimental site, and the blue polygon marks the control site. Yellow circles indicate the number of hatched eggs (larger circles denote more eggs)

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

- A. The average lifespan of males of *Aedes albopictus* positively correlates with the effectiveness of IIT.
- B. Reducing the initial irradiation dose can lead to resistance against the *Wolbachia* strain in successive mosquito generations.
- C. When 50% of males and females are infected (1:1 sex ratio), 75% of matings produce no offspring due to cytoplasmic incompatibility.
- D. Mosquito migration from control site to experimental site is the most likely explanation of the hatched eggs found in the experimental site.

18

Symbiosis and trophic interactions are essential to maintain ecosystems. In this question, you will analyze the complex ecological relationship between whistling thorn trees, acacia ants (which receive nutrition and shelter from whistling thorn trees), megaherbivores (elephants), predators (lions), and their prey (zebras and buffalos) in an African savanna. You know that between 2000 and 2020, big-headed ants, an invasive ant species exterminating acacia ants, increased in number in the region.

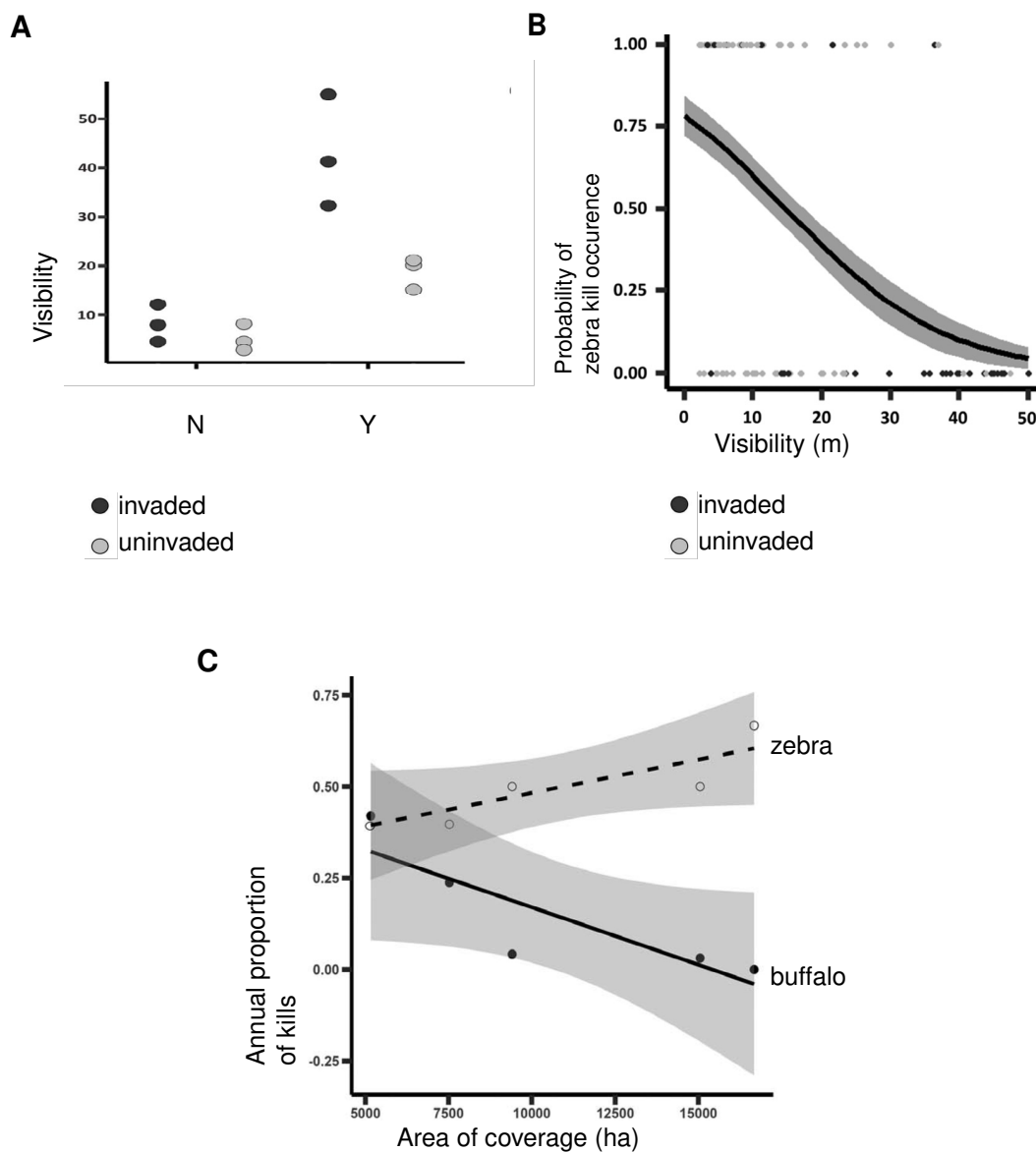


Figure 1. A. Results showing how big-headed ant invasion affects visibility with (Y) or without (N) megaherbivores. The higher the number of whistling thorn trees, the lower the visibility. **B.** Results depicting how visibility affects zebra kill occurrence by lions. **C.** The proportion of prey (zebra or buffalo) killed by lions as a function of areal coverage of whistling thorn trees.



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

A. Based on the given data, the symbiosis between acacia ants and whistling-thorn trees is commensalism (only ants benefit from the interaction).

B. Zebras are more vulnerable to lion predation in big-headed ant-invaded areas.

C. Between 2000 and 2020, lions are expected to shift their prey from buffalos to zebras.

D. The study suggests that lions prefer ambushing zebras to chasing them for long distances.

Ethology

19

Honeybees like *Apis cerana* (Ac) and *Apis mellifera* (Am) defend against hornets (*Vespa velutina*, Vv) by forming a 44°C heat ball and stinging. The effects of heat (25°C or 44°C in thermostatic conditions) and stings from both species on hornet survival were studied (Figure 1A). A mutant *A. mellifera* colony (Amdef) can generate heat but cannot sting and in all other aspects is similar to wild-type ones. Scientists also examined the body mass, venom mass, and stinger length of Ac, Am, and Vv (Figure 1B). Figures 1A and 1B show data for wild-type bees.

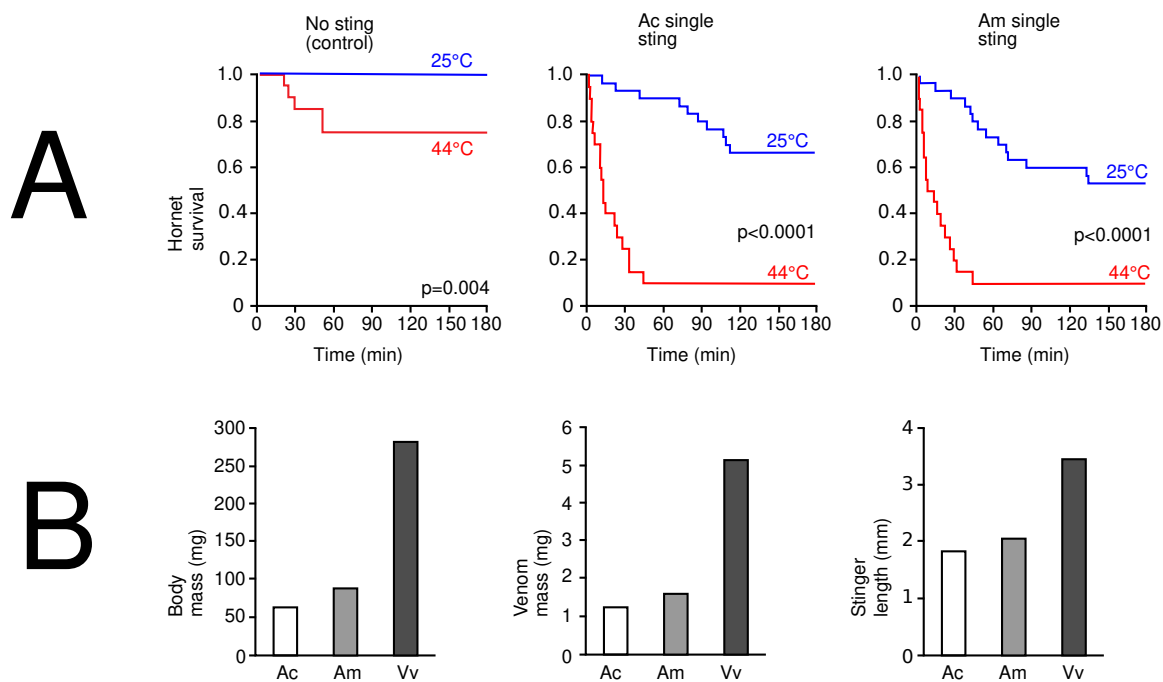


Figure 1. **A** Graphs show the proportion of surviving hornets over time. $p < 0.05$ indicates statistical significance. **B** Body mass, venom mass, and stinger length for three species.

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

- A. Venom mass is 2.6-2.8% of *V. velutina*'s body mass.
- B. *Amdef* bees can't kill any attacking *V. velutina*.
- C. *Amdef* bees kill hornets as efficiently as the *A. cerana* species.
- D. Over 3 hours at 44°C, the same number of *A. cerana* bees can kill more hornets than *A. mellifera* bees.

20

Mating and male-to-male fighting in *Gryllus bimaculatus* are influenced by mating cost, sperm depletion, and female quality. Scientists studied the impact of female body mass on mating behavior (Figure 1A) and the effect of body mass differences in previous male-female encounters on male fighting outcomes (Figure 1B). On average, females are heavier than males. Not all encounters led to successful copulation.

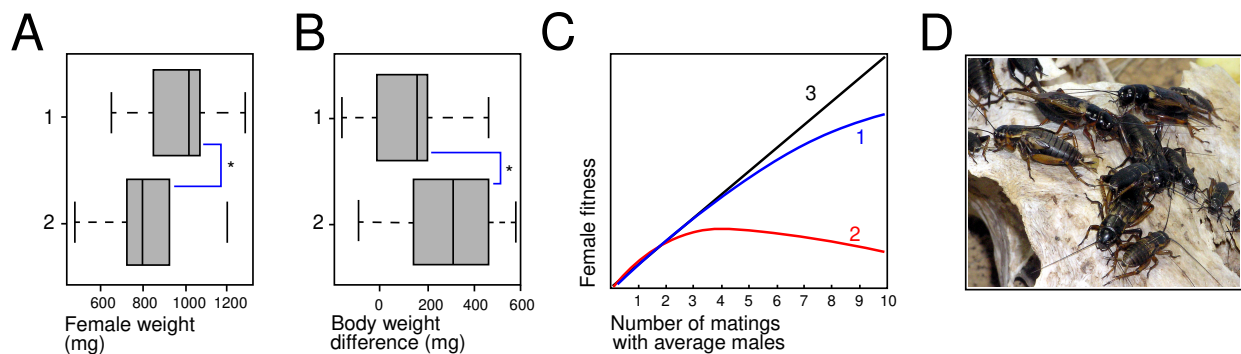


Figure 1. **A** Female weight influence on mating outcome: copulated (1) and not copulated (2). **B** Body weight difference influence on male fighting outcomes: male winning (1) and male losing (2); median – solid line, boxes show 25% and 75% quartiles, * $p < 0.05$. **C** Three hypothetical relationships between female fitness and the number of matings. Line 3 shows a system with an idealized relationship between female fitness and the number of matings. **D** *G. bimaculatus*.

On your answer sheet, indicate if the following statements are True (T) or False (F) based on the data provided. 1.0pt

- A.** The lighter the female, the more chances of being inseminated.
- B.** During male-to-male fights the heavier one on average wins more often
- C.** Measurement of copulation duration is a good indicator of mating cost in terms of sperm depletion.
- D.** If we assume that female of species *G. bimaculatus* displays a type 1 fitness-mating relationship (Figure 1C), then smaller females will have lower fitness compared to large-sized ones

Theoretical Exam - Part B



Q4-3

English (Official)

21

Japanese mitten crabs, *Eriocheir japonica*, can display cannibalistic behavior. The absence of other food resources can greatly facilitate cannibalism. As a result of this, some crabs might be injured or killed. Injury level is not limited to the number of lost extremities but also includes any other forms of it. Figure 1 (A,B) displays the probability of cannibalism versus Factor S.

$$\text{Factor } S = 1 - \frac{\text{prey size}}{\text{predator size}}$$

Figure 1-D shows hypothetical results.

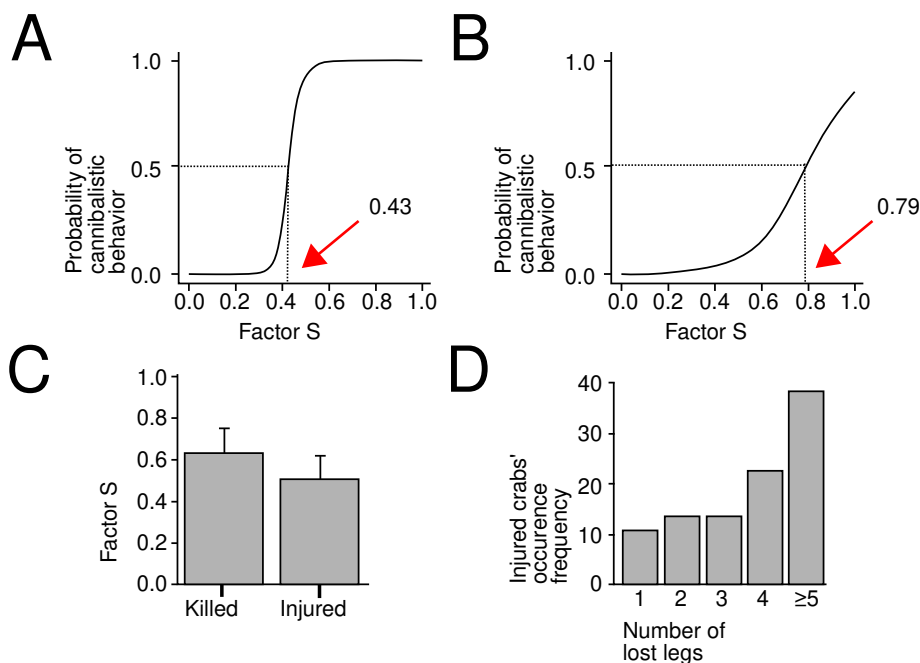


Figure 1. **A,B** Cannibalism among only male (**graph A**) and only female (**graph B**) crabs, n-number of crabs. **C** Y – mean (+SD) of Factor S among killed and injured groups, * $p < 0.05$. **D** Injured crabs' occurrence frequencies.

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

A. Among male crabs, the cannibalism probability is 50% when predator to prey size ratio is about 1.75.

B. Females have a higher eagerness to cannibalism than males

C. In a cannibalistic environment, the occurrence of injured crabs will resemble the frequencies displayed in Figure 1D.

D. The difference in size affects whether the crab is killed or merely injured

Genetics and Evolution

22

Genomic imprinting is one mechanism by which sexes can encourage favourable traits in a fetus to maximize their own reproductive success. The most evident imprinting phenomenon occurs when the normal gene expression is disrupted.

Particularly, Beckwith–Wiedemann syndrome (BWS) is characterized by fetal macrosomia (birth weight >90th percentile) and an increased risk of congenital tumors. Meanwhile, babies with Silver–Russell syndrome (SRS) are born small for their gestational age and later exhibit dwarfism.

Both cases can be associated with genetic defects in clusters of imprinted genes on chromosome 11 (see Fig.1). *IGF2* is a pro-proliferative regulator of fetal growth. *H19* knockout does not have pathological consequences. Another paternally imprinted gene (active on a maternal chromosome) is *IGF2R*; its protein binds *IGF2* and targets it for lysosomal degradation.

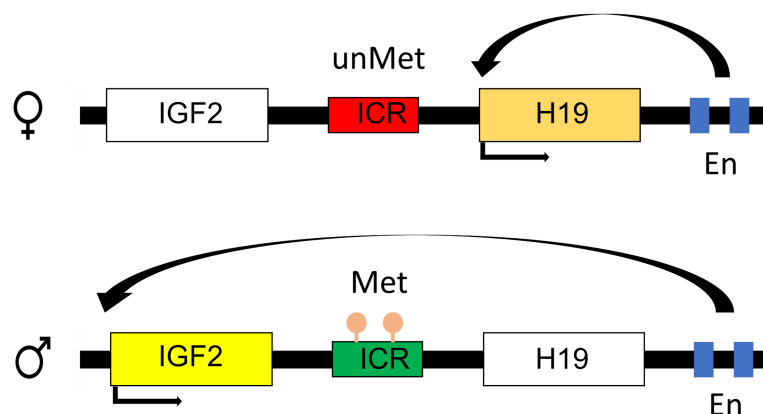


Figure 1. Maternal and Paternal structures of the IGF2-H19 cluster. ICR - imprinting control region; En - Enhancer, Met - methylated, unMet - unmethylated.

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

- A.** The figure implies that male infants are more often prone to cancers.
- B.** Paternal uniparental disomy of chromosome 11, both copies of the pair are inherited from a father, might lead to the symptoms of SRS.
- C.** Individuals with the maternal *IGF2R* loss of function will have the phenotype resembling that of the BWS patients.
- D.** The genome imprinting in monogamous species is expected to occur at lower rates than in polygamous species.

23

Sometimes a formation of multicellular, organized structures can be observed in baker's yeast (*Saccharomyces cerevisiae*) in which newly divided yeast cells do not separate from the parent cell, illustrating a potential transition step from unicellular to multicellular organisms. The emergence of multicellular structures (Figure 1A) in baker's yeast can be influenced by various factors, one of which is a mutation in the *ACE2* gene, responsible for the transcriptional regulation of the protein-coding gene - *CTS1*. To investigate this, scientists crossed different yeast strains and sequenced *ACE2* gene alleles.

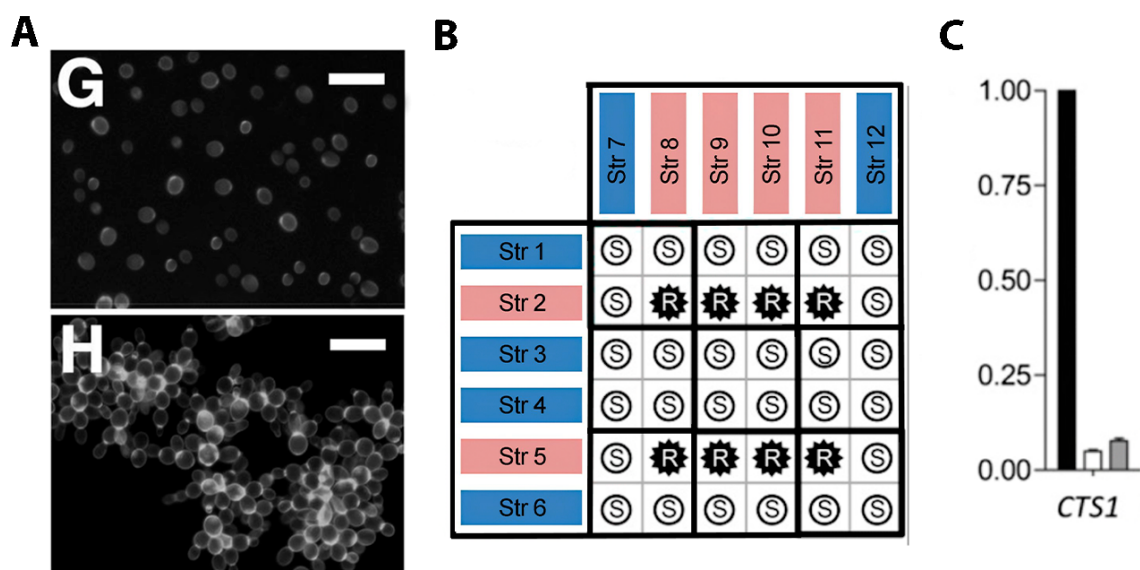


Figure 1. **A** Wild type (G) and *ACE2* mutant (H) yeast cells. The preparations were stained with dye for chitin. **B** Results of crosses between strains: blue - wild type, red - *ACE2* mutants; R - multicellular, S - unicellular offspring. **C** Relative expression level of the *CTS1* gene (black bar indicates the wild type, white and gray indicate two different strains with mutations in *ACE2*).

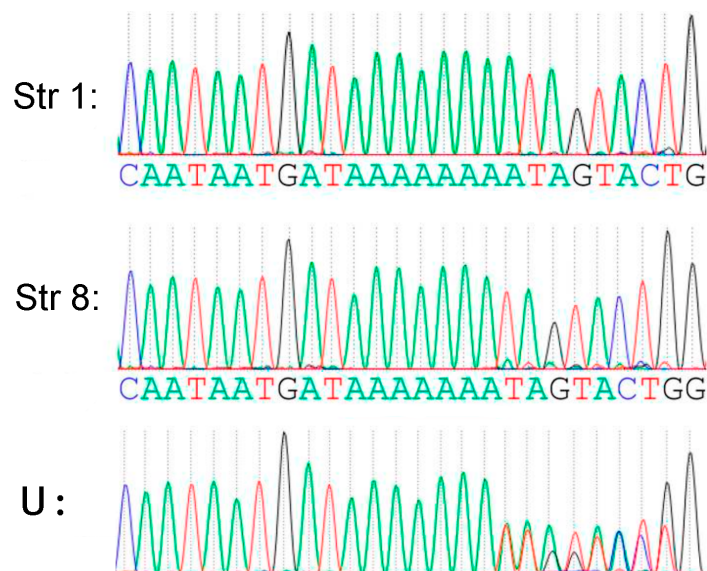


Figure 2. *Ace2* gene region sequencing results; U - unknown.

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

- A.** When subjected to identical incubation conditions, wild-type yeast cultures exhibit a faster settling rate compared to mutant yeast cultures.
- B.** The mutation in the yeast strain 8 causes a frameshift and is recessive.
- C.** The unknown sequencing sample in Figure 2 may be the offspring of a cross between strains 1 and 8.
- D.** The product of the *CTS1* gene likely plays an important role in the final stages of cell division rather than in the initial stages.

24

Robertsonian translocation in human chromosomes occurs when recombination between two acrocentric chromosomes results in the fusion of two long arms and the loss of two short arms (Figure 1). Acrocentric chromosomes are characterized by centromeres positioned close to one end, resulting in notably short second arms. Obvious examples of such chromosomes in humans are chromosomes 14 and 21. Other acrocentric chromosomes have short arms of similar length and no banding pattern.

Table 1 shows information about anomalies associated with chromosomes 14 and 21, and Figure 1B displays the karyogram of one patient's gamete.

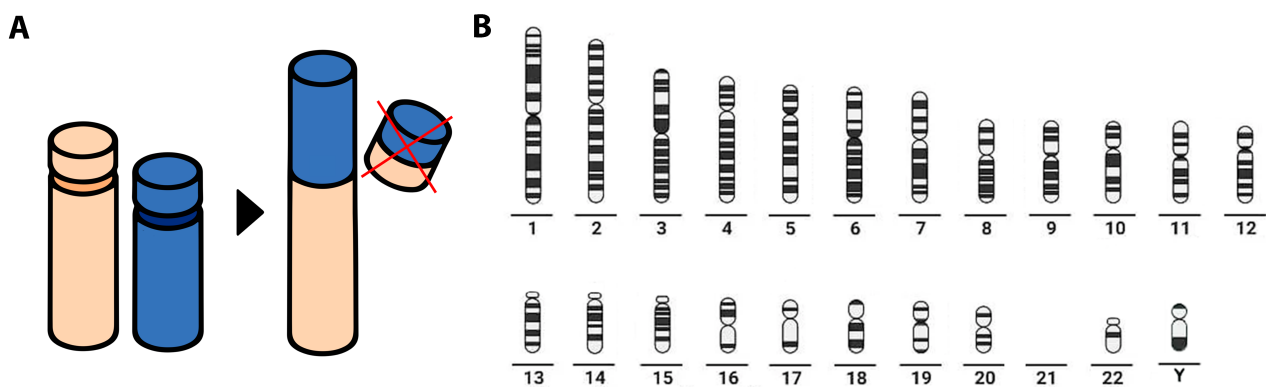


Figure 1. **A** Robertsonian translocation mechanism. **B** Karyogram of a gamete.

Karyotype	Phenotype
Trisomy 14 ($2n + 1$)	Lethal
Trisomy 21 ($2n + 1$)	Down syndrome
Monosomy 14 ($2n - 1$)	Lethal
Monosomy 21 ($2n - 1$)	Lethal
14-21 balanced translocation carrier ($2n - 1$)	Normal

Table 1. Abnormalities of chromosomes 14 and 21.

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

- A.** This type of translocation can also occur with chromosomes 1 and 2.
- B.** Not less than 50% of all possible embryos that can arise from the fusion of gametes from a father with Robertsonian translocation 14-21 and a healthy mother are lethal.
- C.** In order to determine the cause of the appearance of this karyogram in Figure 1B, it is necessary to carry out karyotyping of the patient's and his parents' somatic cells.
- D.** In total, 15 different types of Robertsonian translocations may occur in human cells.

25

A unique phenotype associated with enhanced performance in labyrinth tasks has been identified in mice. The trait is X-linked (Figure 1).

Scientist A introduces 500 male and 500 female mice to an island. The initial allele frequencies in this population are $p = 0.7$ (dominant allele) and $q = 0.3$ (recessive allele). Subsequently, Scientist B brings another 500 male and 500 female mice which were drawn from a larger population with allele frequencies $p=0.8$, and $q=0.2$. Both the initial and final populations are assumed to be in Hardy-Weinberg equilibrium. After several generations, the combined population on the island is 2,000 mice (Male/Female=1000/1000).

A female mouse was randomly picked up from Scientist A's mice population before mixing and was crossed with Mouse 3 from the pedigree in Figure 1 (**Cross Q**).

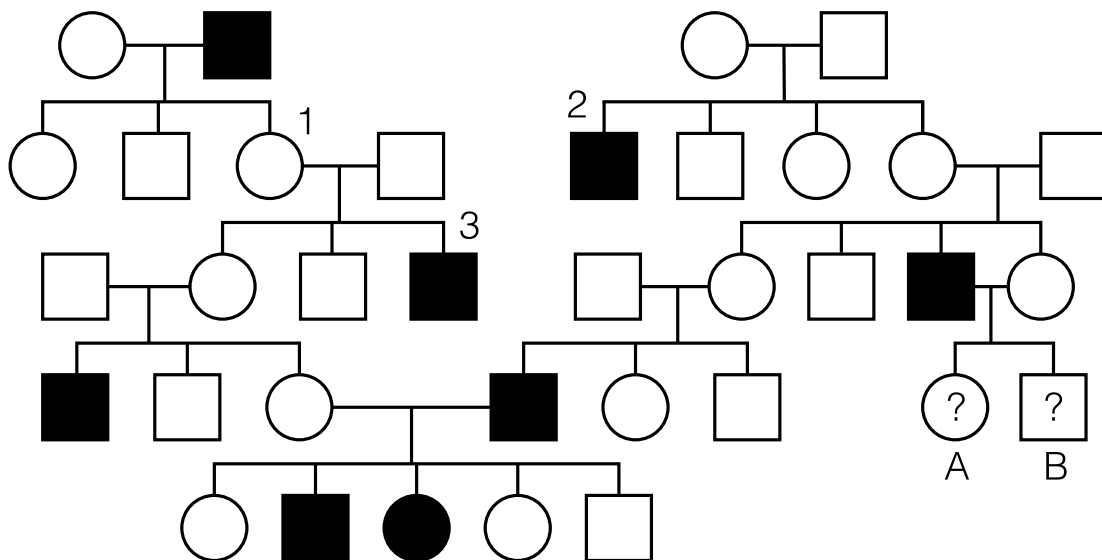


Figure 1. Inheritance mode of "Performant" phenotype (black-colored). Mice have the same XX/XY system as humans.

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

- A.** In the new population of an island, the ratio of "performant" male to "performant" female mice is 5:1
- B.** In the **Cross Q**, the probability that the male offspring will **not** have a "performant" phenotype is 70%
- C.** If a cross between **mice 1** and **2** from Figure 1 produces 4 offspring, the probability that all are "performant" male mice is less than 0.2 %
- D.** The probability of having a "performant" phenotype is the same for **mouse A** and **mouse B**



26

Intratumor heterogeneity refers to distinct tumor cell populations within the same patient's tumor (**Figure 1A**). During tumor evolution, random mutations in genes (A-J in **Figure 1B**) of different tumor cells result in distinct populations of cells (R1-R4 in Figures 1A and B) with different genetic and phenotypic profiles.

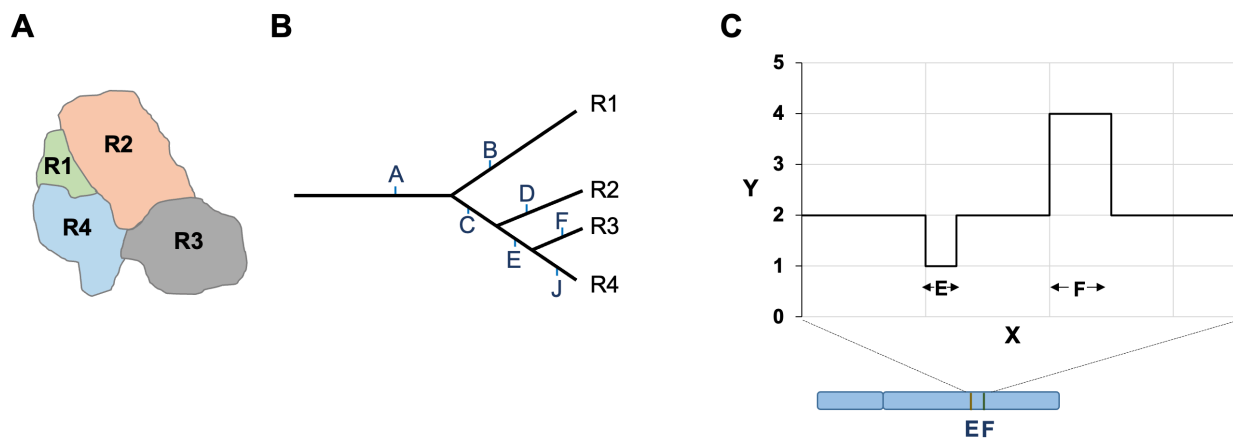


Figure 1. **A.** A hypothetical tumor sample. **B.** The evolutionary relationship between the tumor regions of the sample, shown in A. Labels A-J refer to random mutations in genes of different tumor cells. **C.** The copy number alterations of genes E and F (the number of times a gene is present in the genome) along the chromosome (X: position along the chromosome, Y: copy number) from the tumor sample, shown in A. Note that the genetic defects related to genes E and F are known to be due to copy number alterations.

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

- A.** Intratumor heterogeneity frequently results in treatment failure and drug resistance.
- B.** Mutation in gene D is a better therapeutic target than mutation in gene A.
- C.** After treatment with the drug targeting mutation in gene C, Region R1 is more likely to expand than R4.
- D.** Based on Figure 1C gene E is a potential oncogene, while gene F is a potential tumor suppressor gene.

Theoretical Exam - Part B



Q5-9

English (Official)

27

It is known that human genes H (located on chromosome 1) and K (located on chromosome 5), are highly prone to genomic rearrangements, such as deletions, translocations, duplications, and inversions. From a given population, three individuals (ID-1, ID-2, and ID-3) are known to have genomic rearrangements at these loci. Polymerase Chain Reaction (PCR) was performed to determine the type of rearrangement (**Figure 1B and C**). Primers for PCR were indicated as small arrows in **Figure 1A** (the arrowhead denotes the 3' end of the primer).

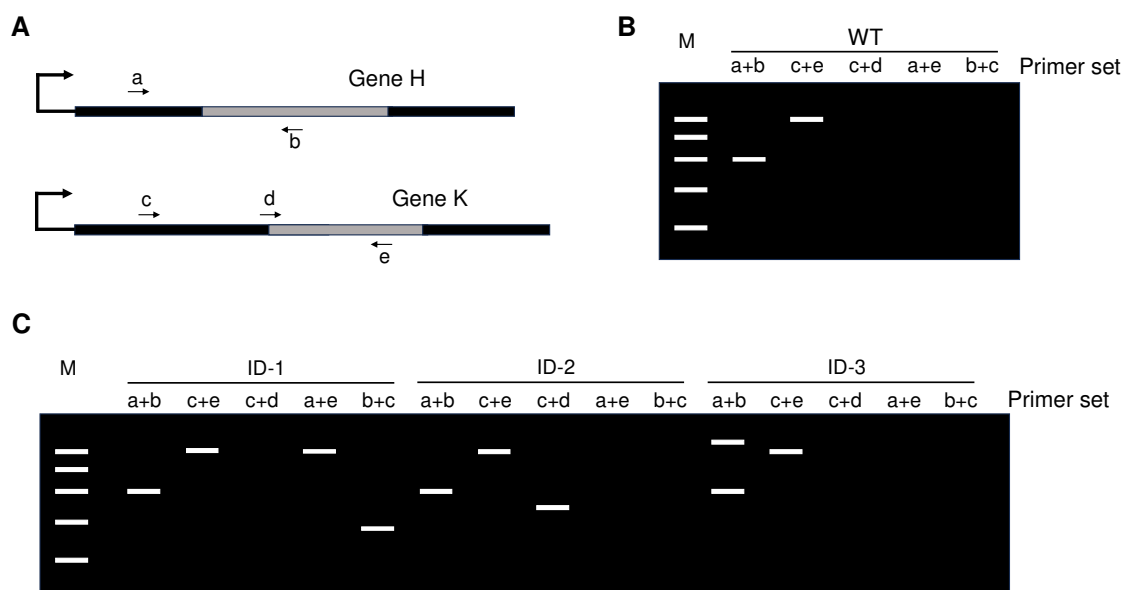


Figure 1. A. The structure of genes K and H, where black regions depict exons, while light gray regions are introns. Note that for both genes, the junction between depicted exons codes for an active site in their respective protein (enzyme) products. **B.** PCR results from a wild-type (WT) individual (M - DNA size marker). **C.** PCR results from three tested individuals (ID-1, ID-2, and ID-3). Note that the intensity of the bands does not represent the amount of DNA.

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

- A.** In ID-1, there is a translocation event between chromosomes 1 and 5.
- B.** ID-2 has an inversion, resulting in a non-functional protein product.
- C.** ID-3 has a deletion.
- D.** ID-1 is homozygous for the rearrangement, while ID-3 is heterozygous.

Theoretical Exam - Part B



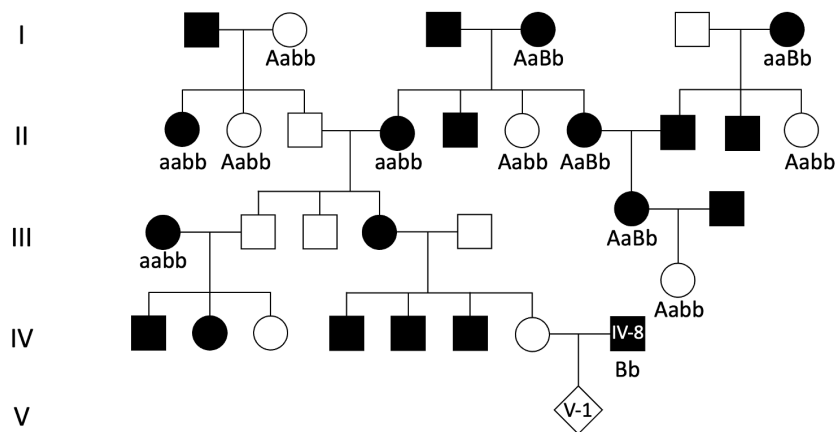
Q5-10

English (Official)

28

In a hypothetical human population genes A and B control hair pigmentation, where hair color can be either black or white. Both genes A and B are autosomal, have two alleles, exert complete dominance, and are unlinked. In addition, these genes follow the Hardy-Weinberg principle and the frequency of the dominant allele of gene A is 0.4.

In this question, you are given a genetic pedigree of individuals from this population, where black squares and circles represent black-haired individuals. Genotypes of some individuals are shown as well. Note, that the genotype of individual IV-8 for gene A is unknown.

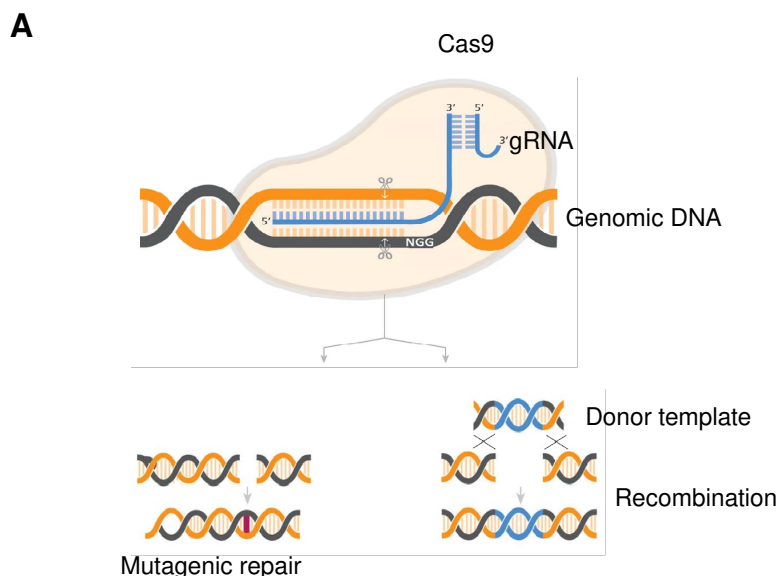


On your answer sheet, indicate "T" for true statements and "F" for false ones. 1.0pt

- A.** There is an epistatic relationship between genes A and B.
- B.** The probability that double heterozygous parents will have a child with white hair is $\frac{7}{16}$.
- C.** The probability that individual V-1 will have white hair is 0.35.
- D.** Now, assume that you don't know whether gene A is autosomal or X-linked, but you know that it is not located on chromosome Y. In this case, based on the pedigree with the indicated genotypes alone, gene A can be located in every human chromosome except chromosome Y.

29

Cas9 is an enzyme utilized in genome engineering, where it cleaves the DNA at sites complementary to the gRNA sequence (**Figure 1A**). To cleave the DNA, Cas9 requires an NGG (N is any nucleotide) sequence next to the target site (**Figure 1A**). Repair of Cas9-cleaved DNA results in either random mutations or precise introduction of the desired change. The latter requires a donor template having a homologous sequence to the target site (**Figure 1A**).



B

DNA: 5' -GCCACTATGCGATTGCGACACTTACAGGTCAGAGCACATTTCAAAGTTCGGACATAAA-3'
 3' -CGGTGATACGCTAAGCTGTGAATGTCCAGTCTCGTGATAAAGTTTCAAGCCTGTATTT-5'

gRNA 5' -CUAUGCGAUUCGACACUUAC-3'

DN-1: 5' -GCCACTATGCGATTGCGACACTTACAGGTCACCACTATTTCAAAGTTCGGACATAAA-3'
 DN-2: 5' -GCCACTATGCGATTGCGACACTTACAGTCACCAACACATTTCAAAGTTCGGACATAAA-3'

C

WT: 5' -GCCACTATGCGATTGCGACACTTACAGGTCAGAGCACATTTCAAAGTTCGGACATAAA-3'
 Mut-1: 5' -GCCACTATGCGATTGCGACACTTAC___TCAGAGCACATTTCAAAGTTCGGACATAAA-3'
 Mut-2: 5' -GCCACTATGCGATTGCGACACTTACAGGTCAGAGCACATTTCAAAGTTCGGACATAAA-3'
 Mut-3: 5' -GCCACTATGCGATTGCGACTTTACAGGTCAGAGCACATTTCAAAGTTCGGACATAAA-3'
 Mut-4: 5' -GCCACTATGCGATTGCGACCTTA___GTCAGAGCACATTTCAAAGTTCGGACATAAA-3'

Figure 1. A. Repair outcomes of Cas9-mediated DNA cleavage. **B.** The DNA sequence encoding an N-terminal fragment of the target protein, the gRNA sequence (highlighted in green), and two donor sequences (DN-1 and DN-2) having the desired change highlighted in blue (the sequences highlighted in orange are silent mutations introduced to the Donor sequences) are shown. The trinucleotide highlighted in red is NGG. **C.** The random mutational outcome (in pink) at the Cas9-mediated cleavage site without supplying donor sequence is represented.

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

- A.** There are a total of two Cas9-targetable sites in the given DNA.
- B.** DN-2 is a better choice than DN-1 for introducing the desired mutation.
- C.** Mutation in Mut-2 is potentially more deleterious than mutation in Mut-3 (find the start codon).
- D.** Mutation in Mut-4 is potentially more deleterious than mutation in Mut-1 (find the start codon).

Theoretical Exam - Part B

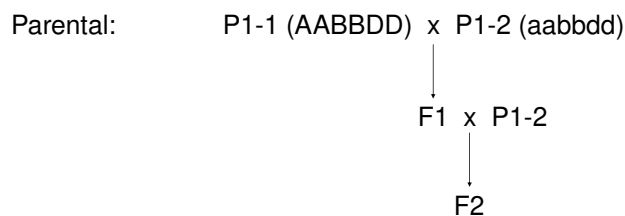


Q5-13

English (Official)

30

In some fruit flies, wing pigmentation is controlled by genes A, B, and D, which are linked on the same chromosome. One of the genes codes for an ENZYME, converting yellow pigment to orange. The other two genes code for an INHIBITOR of ENZYME and an ACTIVATOR of ENZYME. ACTIVATOR acts by inhibiting INHIBITOR. Moreover, one of them has a redundant role in larval development with the gene E which is located on a separate chromosome (larvae do not survive when both of the genes are in recessive state). Gene E has no role in wing pigmentation. The recessive allele of all these genes results in a non-functional protein product. The parental cross scheme and the results of the F₂ generation are shown below.



Wing pigmentation	Genotypes	Offspring number (when both P1 parents are EE)	Offspring number (when both P1 parents are ee)
Orange	ABD/abd	200	200
Yellow	abd/abd	200	0
Orange	AbD/abd	33	30
Yellow	aBd/abd	31	0
Orange	Abd/abd	16	0
Yellow	aBD/abd	16	19
Yellow	ABd/abd	1	0
Yellow	abD/abd	1	1

Table 1. Phenotype and genotype distribution of the F₂ generation.

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

- A.** The recombination frequency between genes A and B is 20%.
- B.** The protein product of gene B is ENZYME.
- C.** 50% of the offspring of the cross between AAbbDdEE and aaBbddEE should have orange wings.
- D.** All the offspring of the cross between AaBbDDEe and AABbddEe should be viable.

Theoretical Exam - Part B



Q5-14

English (Official)

31

Linkage Disequilibrium (LD) is a non-random co-occurrence of alleles at different loci. Loci can be on the same or separate chromosomes. Let's consider biallelic loci R and Q, located in the same chromosome. Around 1000 years ago, a neutral mutation (M^*) arose in a single human individual (ID-1) at a locus M, which is located between R and Q. ID-1 was homozygous at R and Q. **Table 1** shows the frequency of association between M and R/Q in chromosomes of today's 200 heterozygous carriers of M^* , who inherited M^* from ID-1. Assume that there is no selection against any allele at loci R, Q, and M. Also, the population size is infinite.

Allele pair on the same chromosome	Frequency
R1- M^*	12
R2- M^*	188
Q1- M^*	164
Q2- M^*	36

Table 1. Occurrence of R/Q alleles paired with M^* allele from 200 heterozygous carriers descended from ID-1

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

- A.** If, in a population, the frequency of gametes having dominant alleles of genes A and B together is equal to the product of frequencies of these alleles, then there is no LD between dominant alleles of genes A and B.
- B.** The genotype of ID-1 is most likely R2R2/Q1Q1.
- C.** M is closer to locus Q than to locus R.
- D.** In the next 1000 years, you can expect LD between M^* and R/Q alleles to decrease.

Plant Anatomy and Physiology

32

Venus fly trap is a carnivorous plant. In an experiment, researchers measured how venus fly traps close at different temperatures (Figure 1-A and Figure 1-B) and in response to electrical stimulation (Figure 1-C). The soil was treated with substance A for 4.5 hours before the electrical stimulation (curve 3, Figure 1-C). After that, soil in the vicinity of the Venus trap was washed several times with distilled water (curve 4, Figure 1-C).

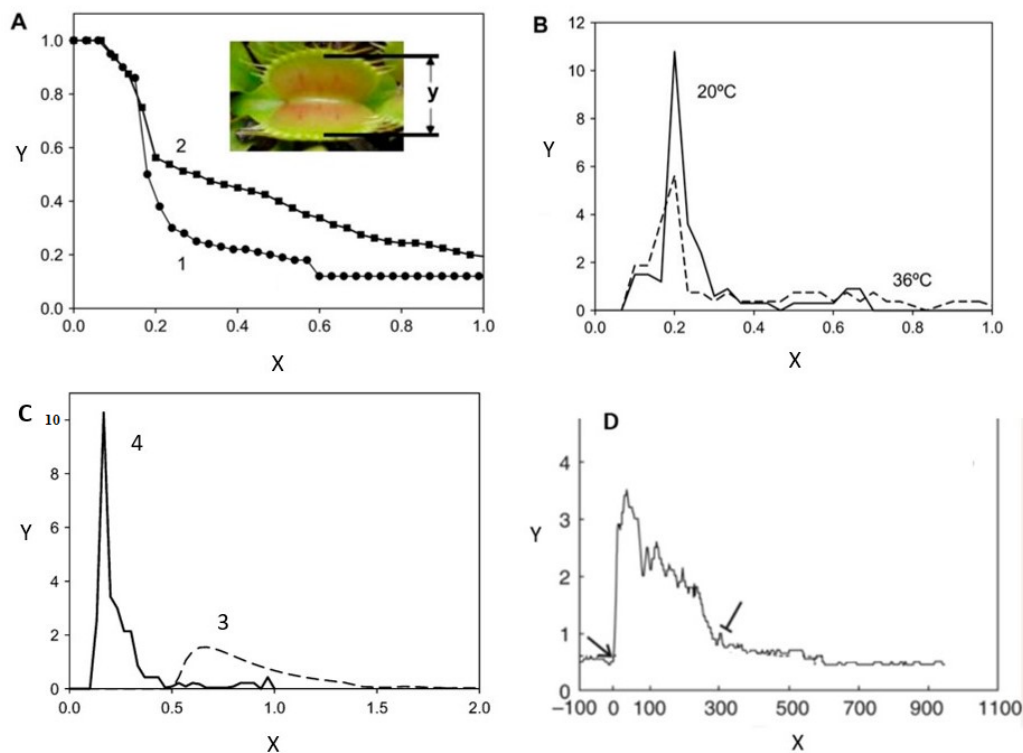


Figure 1. For **A**, **B**, **C** X – Time (s) after stimulation. **A** Trap closure after an electrical stimulation at temperatures 20°C and 36°C. Y – $y/y_{\max}$. When the trap is most widely open, the distance is $y_{\max}$. **B** The same data from graph A with temperature influence on the speed of trap closure. Y – speed (1/s). **C** Trap closure due to electrical stimulation. Y – speed (1/s). **D** Y – Rate of respiration ($\mu\text{mol}/\text{m}^2 \cdot \text{s}$) in trap leaf due to the repeated trigger hair stimulation in closed traps. X – Time(s). Arrow – stimulation begins, blunted arrow – stimulation ends.



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

A. On graph A curve 1 is obtained under 20°C, while curve 2 is under 36°C

B. The effect of substance A is irreversible

C. Substance A delays the trap closure but does not affect the speed of the closure

D. Graph D shows that there are several causes of increased respiration aside from energy expenditure for trap closure.

33

The vascular cambium is a plant tissue responsible for secondary growth by producing secondary xylem and phloem. Scientists studied how genes *PtrWOX4a* and *PtrVCS2* affect vascular cambium proliferation in *Populus trichocarpa*, a eudicot angiosperm species.

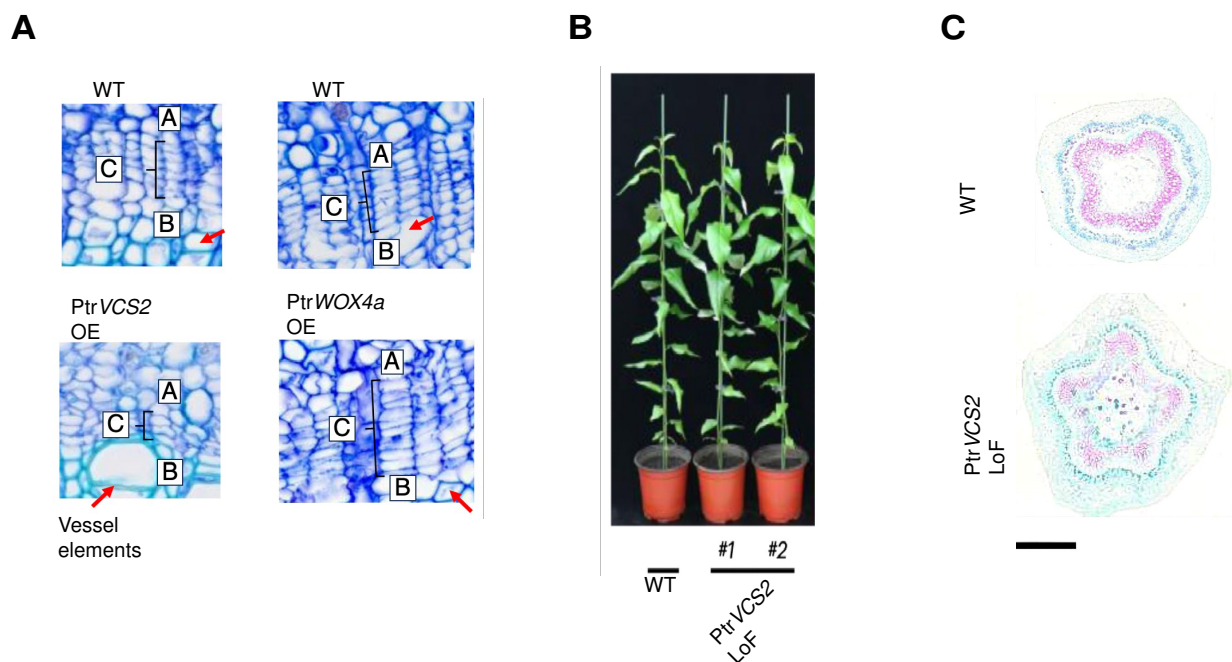


Figure 1. **A** Stem cross-sections of wild-type and indicated mutant plants (C denotes vascular cambium layers, and red arrows indicate vessel elements, WT: wild-type, OE: overexpression). **B** The height of *P. trichocarpa* wild-type and *PtrVCS2* LoF (loss-of-function) mutants. **C** Results showing how a loss-of-function *PtrVCS2* mutant affects the development of secondary vascular tissues in the stem by histological staining with safranin O (red/pink) and fast green, which stain lignified and non-lignified cells, respectively. Scale bar: 1 mm

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

A. In **Figure 1A**, cells in Region A are more prone to rupture than cells in Region B.

B. *PtrWOX4a* and *PtrVCS2* have opposing effects in regulating vascular cambium proliferation.

C. *PtrVCS2* sets the upper limit for primary and secondary growth.

D. Enhanced vascular cambium proliferation accelerates secondary xylem development.

34

Scientists studied how GAPLESS proteins affect apoplastic transport (transport through cell walls and extracellular space) of nutrients via endodermis. First, they monitored the penetration of red dye into roots by examining cross-sections at two different positions (depicted as A and B in **Figure 1**) from the same root of a wild-type plant. Next, they analyzed how GAPLESS proteins affect red dye penetration into roots (**Figure 2**). In both Figures, yellow arrows indicate an endodermal cell layer.

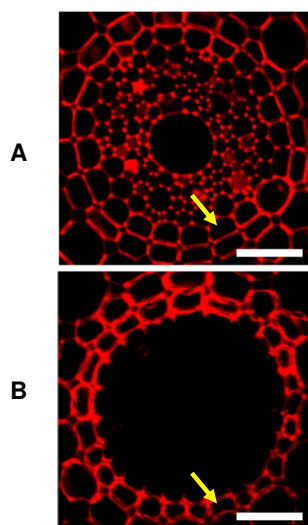


Figure 1

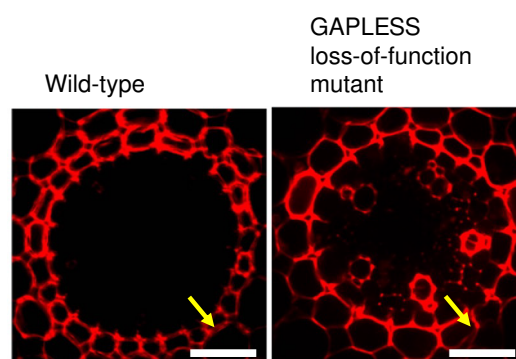


Figure 2

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

- A. The red dye used in the experiment is a small, non-polar molecule.
- B. In **Figure 1**, position B is closer to the root tip than position A.
- C. Based on **Figure 2**, GAPLESS proteins prevent the transport of substances from the cortex to the vascular system via the apoplast.
- D. The stem of the plant species used in this study most likely increases in diameter year by year.

35

Phytochrome B (phyB) is a plant photoreceptor responsible for numerous physiological aspects of plant growth. PhyB exists in two states, P_r and P_{fr} , the interconversion of which is regulated by red and far-red light (**Figure 1A**). Interestingly, temperature can also affect the interconversion between P_r and P_{fr} . At the cellular level, PhyB forms structures called nuclear bodies (NB, **Figure 1E**).

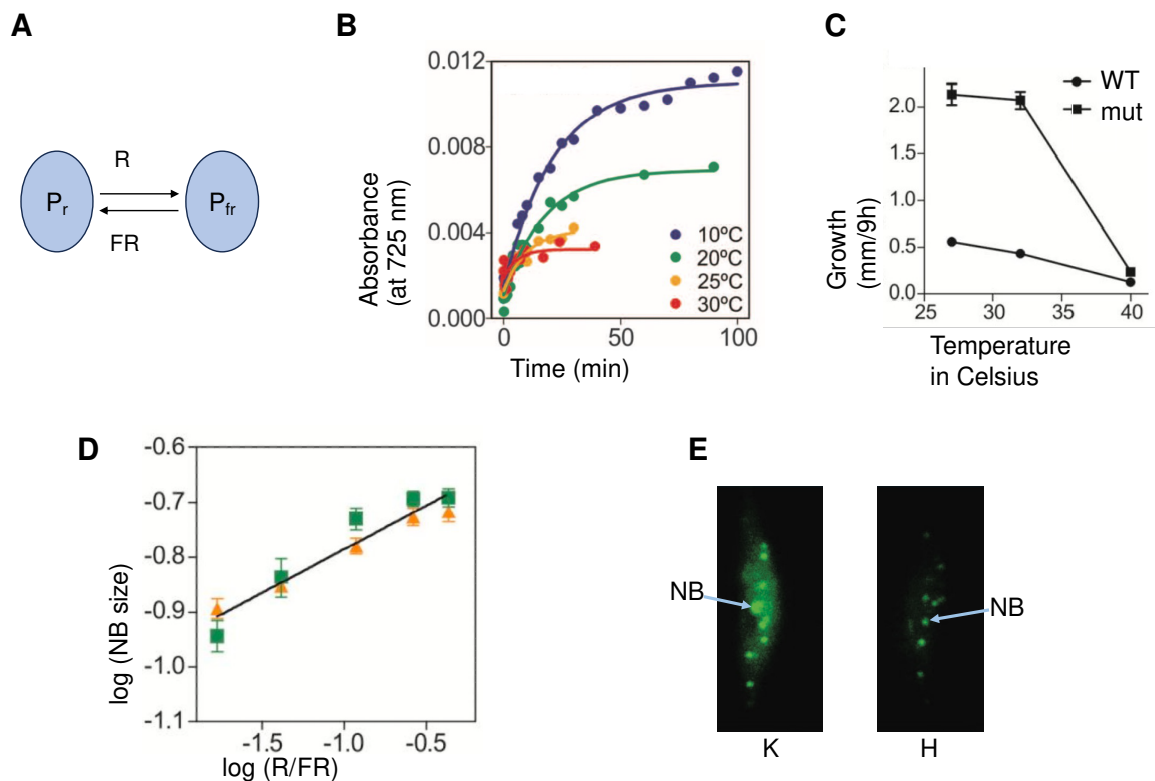


Figure 1. **A** The control of PhyB states by red (R) and far-red (FR) light. **B** The effect of temperature on the absorbance of PhyB at 725 nm light (far-red). In each condition, an equal amount of PhyB was used. **C** Hypocotyl growth in wild-type (WT) and phyB null mutant (mut) seedlings. **D** The impact of the ratio of red-to-far-red light on the size of NBs in temperature-insensitive PhyB mutants (only light controls P_r and P_{fr} interconversion in these mutants). **E** The NBs from two different wild-type plants grown under different conditions.

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

A. Red light has the opposite effect in determining the phyB (P_r or P_{fr}) state to the increase in temperature.

B. PhyB negatively impacts hypocotyl growth.

C. NBs are constituted predominantly of P_r

D. In **Figure 1E**, plant K was more likely to grow under canopy shade conditions than plant H.

36

Researchers studied the effect of photoperiod and CONSTANS (CO) protein, a critical mediator of photoperiodic cues, on seed mass and size.

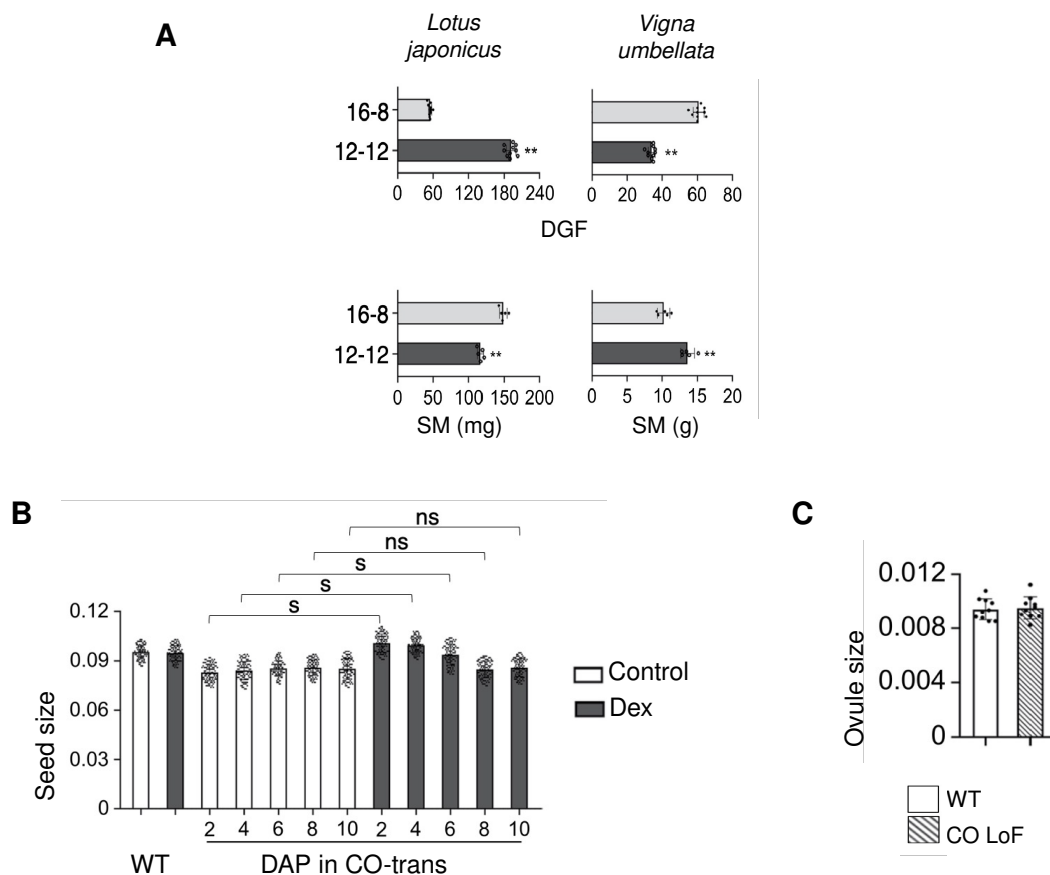


Figure 1. A The flowering time and seed mass of two different plant species grown under 16-hour-day-8-hour-night (16-8) and 12-hour-day-12-hour-night (12-12), representing long-day and short-day photoperiodic conditions (DGF: days between germination and flowering, SM: seed mass). **B** Results showing how CO in seeds affects seed size (mm^2). Here, they used wild-type (WT) and CO-transgenic (CO-trans) seeds. In CO-transgenic seeds, CO is only functional upon incubation of seeds with the compound Dex. (DAP: days after pollination). s and ns depict significant and non-significant differences between compared samples. **C** Mature ovule size (mm^2) of wild-type (WT) and CO loss-of-function (Co-LoF) mutants.

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

A. Compared to short-day conditions, long-day conditions enhance flowering and increase seed mass for *Vigna umbellata*.

B. Disrupting the nighttime right in the middle with a flash of red light should accelerate flowering in *Lotus japonicus* under 12-hour-day-12-hour-night conditions.

C. The activity of the CO is more crucial in the earlier stages of embryo development than in the later stages.

D. CO regulates seed size both before and after double fertilization.

37

Auxin promotes and cytokinins repress apical dominance. To further understand how auxin and its transport exert apical dominance, scientists treated nodal stem sections containing axillary buds with auxin from either end (depicted as A and B in **Figure 1**) in the presence or absence of auxin transport inhibitor, NPA, and measured the auxin content in buds and stems separately. For stems, auxin content was measured at the opposite end to the treatment end. (**Table 1**).

Next, they observed how grafting between Col (wild-type) and *axr1-mut* (auxin-insensitive mutant, which can still produce auxin) affects stem branching (**Figure 2**).

Finally, they tested how tissue-specific expression (**compare Tables 2 and 3**) of the *AXR1* (auxin-sensitive) gene affects stem branching in transformed *axr1-mut* mutants.

	Auxin content in buds		Auxin content in stems	
	End A	End B	End A	End B
- NPA	14.2±0.9	15.8±2.4	2221.0±232.3	13.4±0.5
+ NPA	11.9±0.8	13.5±0.2	31.5±2.93	16.3±0.7

Table 1. Ends A and B indicate auxin-injection points. Values are in counts per minute +/- standard error.

Figure 1

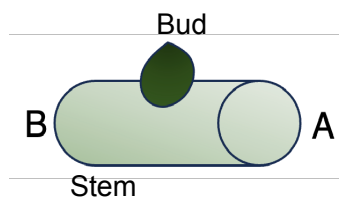
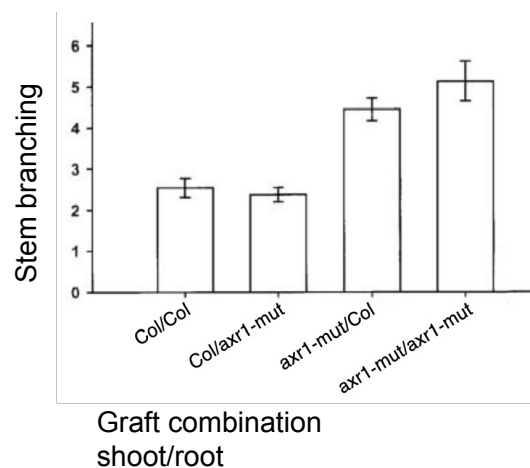


Figure 2



Theoretical Exam - Part B



Q6-10

English (Official)

Sample	Stem branching
Wild-type (untransformed)	16±0.5
Mutant axr1-mut (untransformed)	26±2.0

Table 2. Influence of mutations on stem branching.

AXR1 expressing tissues in transformed axr1-mut mutants					Stem branching
Epidermis	Cortex	Phloem	Xylem	Pith	
O	O	O	O	O	18±1.0
O	X	X	X	X	25±1.0
X	X	O	X	X	25±1.0
X	X	X	O	X	16±0.5

Table 3. O: AXR1 is expressed, X: AXR1 is NOT expressed

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

- A.** End A is closer to the shoot apical meristem than end B.
- B.** Auxin does not enter into the bud to inhibit axillary bud growth.
- C.** Based on the data, auxin potentially suppresses bud growth by inhibiting cytokinin biosynthesis in the root.
- D.** The xylem is critical in mediating the inhibitory action of auxin on bud growth.

38

Kazakhstan is one of the significant contributors to global wheat production and export. Researchers at Kazakh National University studied how chemical A affects wheat (*T. aestivum*) development.

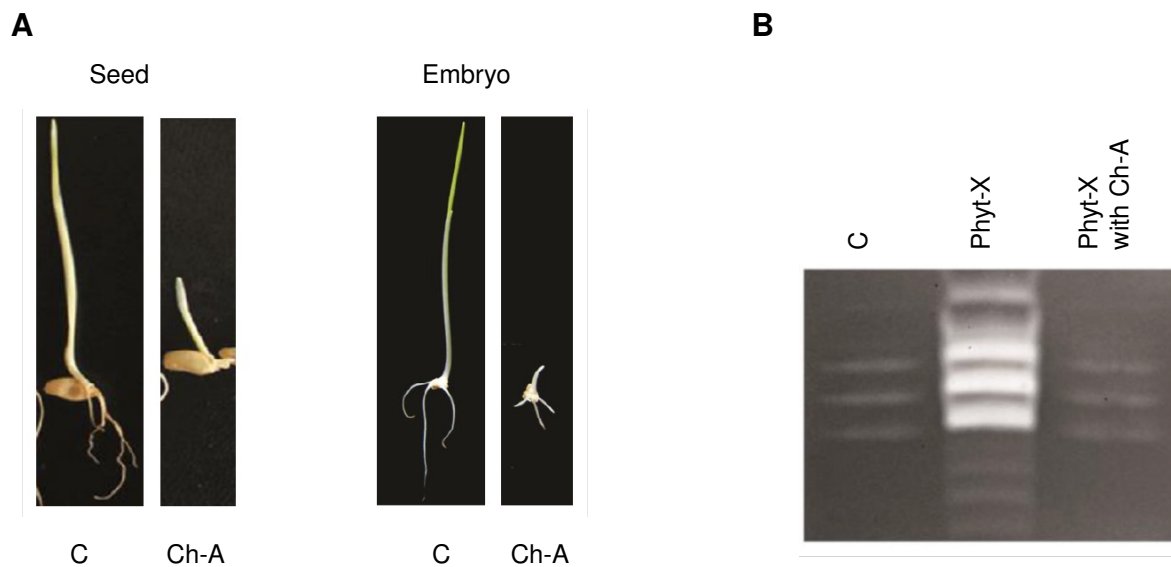


Figure 1. **A** The impact of chemical A (Ch-A) on the germination of seeds and isolated embryos (C: Control). **B** The effect of chemical A on α -amylase activity in seeds (C: Control). A simplified procedure follows: wheat embryos were treated with chemical A and/or phytohormone X (Phyt-X, you need to identify which phytohormone to be able to answer one of the questions below), then total proteins were extracted and separated with a polyacrylamide gel electrophoresis (PAGE). Next, the gel was immersed in the starch solution. Then, an iodine solution was added to the gel. Iodine reacts with starch, producing a dark black color and preventing a bright white color (as shown in **Figure 1B**). Note that glucose does not react with the iodine.

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

- A.** Adding chemical A to the soil can reduce wheat cultivation time.
- B.** The seed coat to some extent imposes a barrier for chemical A.
- C.** In Figure 1B, the phytohormone X is more likely to be abscisic acid than gibberellin.
- D.** In Figure 1B, proteins are denatured and linearized before running PAGE.

Animal Anatomy and Physiology

39

A 65-year-old man with increased plasma cholesterol levels presented with severe pain in his left leg that occurred after walking for 15 minutes and was relieved by rest. Repeated pulse pressure measurements showed significantly lower pressure in the left leg compared to the right leg and left arm, both of which were within the normal range. He was diagnosed with intermittent claudication (a symptom of a range of diseases) – intense pain due to the build-up of metabolic acids. Treatments for cardiovascular diseases include:

- 1) Beta-1 blockers - systemically reduce tension in smooth muscles of blood vessels.
- 2) Aspirin - inhibits prostaglandin synthesis (Table 1) and blood clot formation.
- 3) Statins - decrease blood cholesterol.

Receptor type	Sensitivity threshold without PGs	Sensitivity threshold with PGs
Peripheral chemoreceptors	pH below 6.9	pH below 6.9
Heat receptors	46°C	38°C
Mechanoreceptors	8 millinewton	3 millinewton

Table 1. Thresholds (in respective units of measurement) of pain receptors with and without prostaglandins (PGs).

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

A. Aspirin and statins can be used to minimize further progression of the condition, but not to completely cure it.

B. Aspirin is not an efficient painkiller for episodes of intermittent claudication.

C. Intermittent claudication is a direct result of systemic hypertension in this patient.

D. If the patient had a chronic heart failure (reduced pumping ability of the heart), beta-1 blockers might have been used as a long-term treatment.

40

Pharmacokinetics studies drug movement in the body, guiding dosage for desired effects based on biochemical properties. Table 1 shows pharmacokinetic properties that regulate the duration of a drug's therapeutic effect.

Property	Description
Absorption	Influenced by ionization and other biochemical properties of the compound
Distribution	Influenced by polarity, transport protein binding, and blood flow. The volume of distribution (V) describes a drug's ability to disperse within body fluids. A V close to the total body volume indicates the best distribution.
Metabolism	Primarily occurs in the liver. First-pass metabolism happens when the liver metabolizes a drug before it enters systemic circulation. The drug's half-life is the time for its concentration in the blood to halve. A prodrug is a drug that becomes active after being metabolized (typically in the liver).
Excretion	Kidneys typically eliminate hydrophilic substances, while hydrophobic ones exit via bile. Only 5% of bile salts (as well as drugs) are excreted, with the remainder reabsorbed, transported to the liver, and secreted again with bile. This is known as enterohepatic circulation .

Table 1.

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

A. Oral administration is generally more suitable for prodrugs with high first-pass metabolism than for those with low first-pass metabolism.

B. Drugs that bind strongly to plasma proteins have a small volume of distribution.

C. Lipophilic drugs that do not bind to plasma proteins are expected to have a shorter half-life compared to lipophilic drugs that can bind to plasma proteins.

D. Enterohepatic circulation of oestrogen-containing oral contraceptives prolongs their activity.

Theoretical Exam - Part B



Q7-3

English (Official)

41

Scientists have studied the Burmese Python's heart size changes due to different feeding regimes which are either fed (last feeding 3 days ago) or fasting (last feeding 28 days ago).

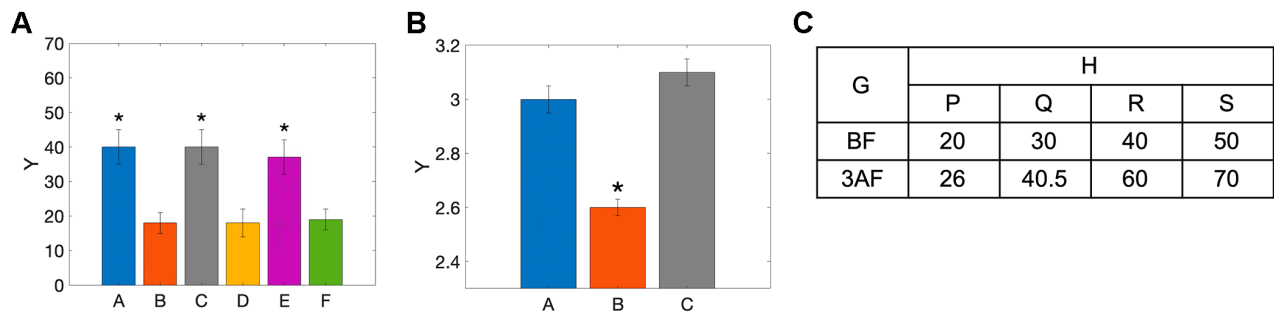


Figure 1. **A** Percentage change in python heart mass (Y-axis) compared to the fasting state due to feeding regimes. X-axis: A - fed pythons, B - fed pythons infused with BSA + *substance Z*, C-F are all fasting pythons infused with: (C) plasma from fed pythons, (D) BSA, (E) BSA + *Substance W*, (F) plasma from fasted pythons. **B** Python's relative heart DNA mass measured at different time points. Y-axis: Relative DNA (ng/mg of ventricular tissue). X-axis: A - fasting python, B - 3 days after feeding, C - 28 days after feeding. **C** Heart masses (in grams) of some animals (P, Q, R, S), including Burmese Python, before feeding (BF) and 3 days after feeding (3AF). G - feeding state, H - animal heart masses (g). (* indicates significance, BSA - bovine serum albumin)

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

- A.** An increase in heart mass of pythons is likely to be due to the increase in cell size.
- B.** Minimal heart mass increase after feeding occurs in animal P among other animals presented in figure 1-C.
- C.** Animal R corresponds to Burmese Python.
- D.** Fed python's plasma might contain substance W.

Theoretical Exam - Part B



Q7-4

English (Official)

42

Human bodies have different types of capillaries that differ in wall structures, depending on the function of the organ they are located in.

Oncotic pressure is a pressure driven by proteins in the solution.

Below you can see the Starling equation, which governs the fluid exchange across capillaries:

$$J_v = K_f((P_c - P_i) - \sigma(\pi_c - \pi_i)) \quad (1)$$

where,

K_f	filtration coefficient
P_c	capillary hydrodynamic pressure
P_i	interstitial hydrodynamic pressure
π_c	capillary oncotic pressure
π_i	interstitial oncotic pressure
σ	reflection coefficient

When J_v is positive, there is a net fluid movement out of the capillary (filtration), and when J_v is negative, there is a net fluid movement into the capillary (absorption).

In a simple model, P_c is influenced by arterial and venous pressures, and can be summarized by the following formula:

$$P_c = \frac{0.2P_a + P_v}{1.2} \quad (2)$$

where P_a and P_v - arterial and venous pressures, respectively.

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

- A.** In a person with a very low protein content in their diet for a long period of time, the filtration level tends to be increased.
- B.** Capillary wall integrity might directly affect the K_f value.
- C.** Venous constriction has a more pronounced effect on P_c value than arterial constriction.
- D.** Fluid exchange between capillaries and plasma protein-synthesizing liver cells is governed mainly by hydrodynamic pressures rather than oncotic pressures.

43

In the liver lobule, 75% of the blood comes via the portal vein located within the portal triad and 25% comes from the hepatic artery. The portal triad consists of a hepatic artery, a portal vein, and a bile duct. The portal vein carries blood from the intestine and stomach, while the central veins carry blood from the liver cells. Functionally, in the lobule, there are zones: 1, 2, 3 (Figure 1a). Figure 1c shows bile flow in different animals.

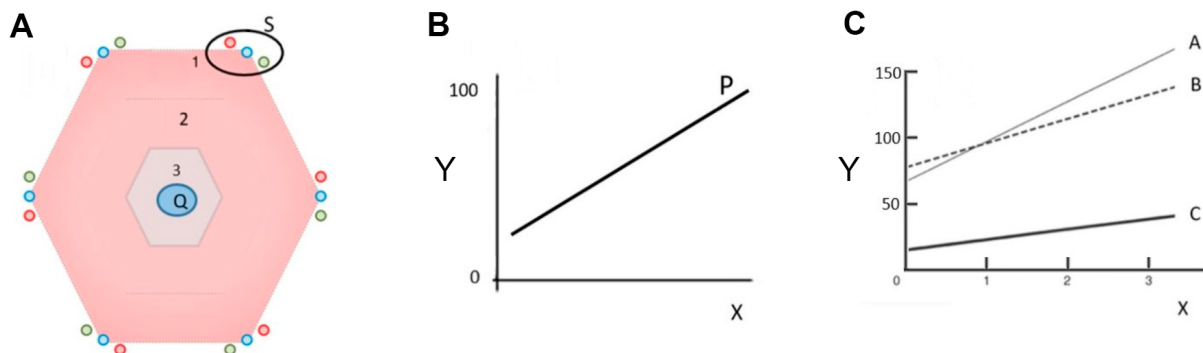


Figure 1. **A** S – portal triad; Q – central vein; 1 – periportal zone; 2 – middle zone; 3 – perivenous zone. **B** Y – circulating toxic substance concentration (%); X – distance from the central vein. **C** Y – Bile flow ($\mu\text{L/kg/min}$); X – Bile salt secretion ($\mu\text{mol/kg/min}$); A – Rabbit; B – Rat; C – Human. "kg" in units refers to kg of liver.

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

- A.** In a person suffering from prolonged hypoxia, zone 2 will mainly be affected due lack of oxygen.
- B.** If a person accidentally intakes an organic toxic substance, then Line P will display its relative concentrations in the liver lobule.
- C.** If both rabbits and rats are in a situation unable to secrete any bile salts, then bile flow will be lower in rats.
- D.** A student (with liver mass = 1.5 kg, bile production rate = $17 \mu\text{L/g Liver/h}$) will produce 17 ml of bile after 40 min of solving IBO questions.

44

Bees can redirect excess heat from the thorax to the abdomen, thus maintaining heat homeostasis. Figure 1-A shows body temperature differences due to various outside temperatures for a bee with a large body mass. Figures 1-B and 1-C show how body mass influences other parameters (see the graphs). Figure 1-D shows how thorax temperature affects the mass-specific metabolic rate. There are mutant bees with a mutation that impairs both effective thorax cooling and abdomen warming. All graphs below show data for wild-type bees without any mutation.

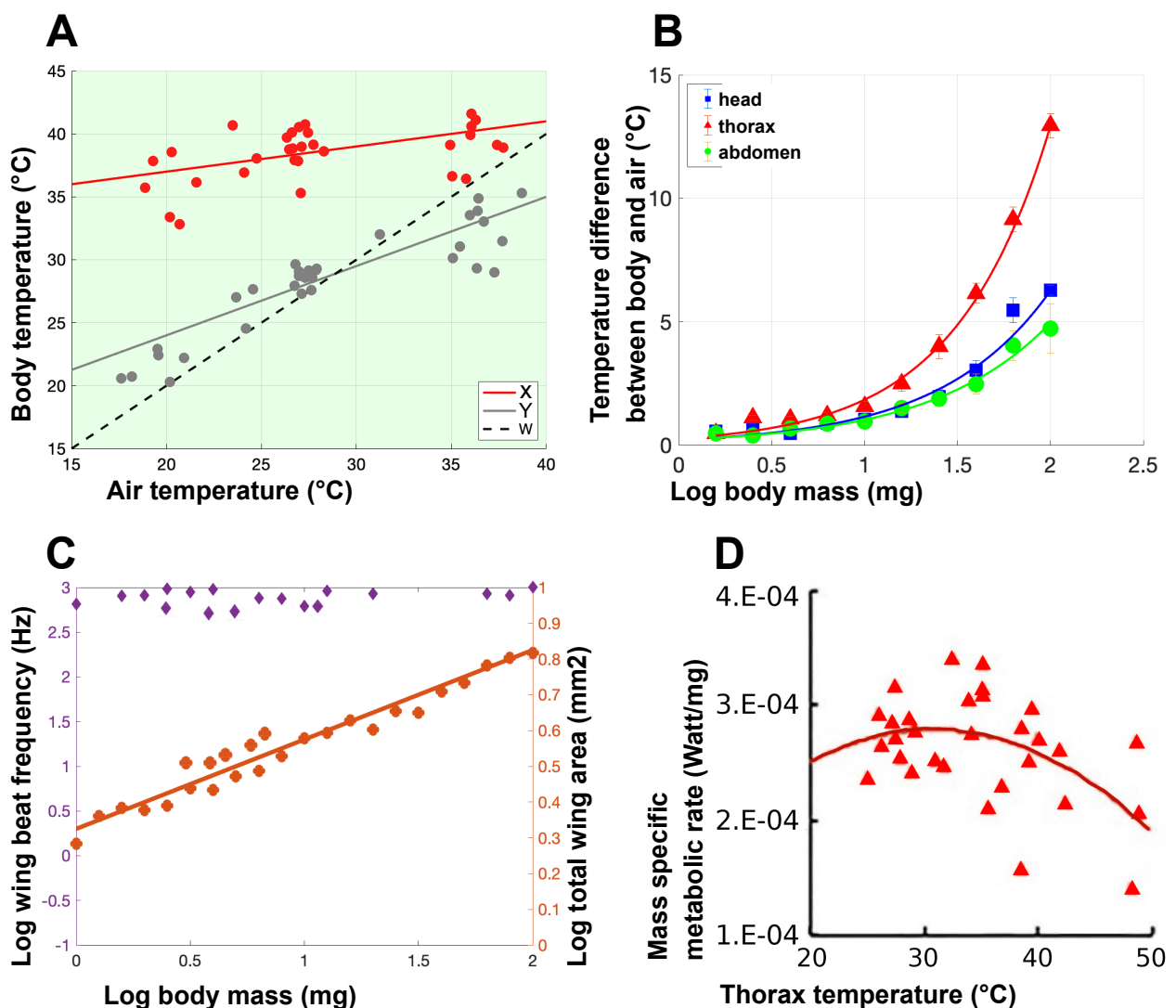


Figure 1. A X – thorax, Y - abdomen.

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

A. The smaller the bee, the lesser the mut99 mutation impact on heat homeostasis.

B. Abdomen temperature for large-sized mut99-bee would likely follow the line W in figure 1-A.

C. Mut99-bee during intensive flight can attain an even higher metabolic rate in the thorax than a normal bee.

D. Smaller bees lose more heat due to a higher surface-to-volume ratio, thus they compensate for it by a higher frequency of wing beat.

45

Lung volumes can change in Chronic Obstructive Pulmonary Disease (COPD). Figure 1 summarizes normal lung volumes (A) and changes that occur at different stages of COPD (B). Figure 1C shows the pressure-volume curve with end-expiratory lung volume (EELV) values for two individuals (1 and 2).

Lung volumes of mild, moderate, and severe COPD patients were studied under rest, with 1/3 maximal power output ($\frac{1}{3} W_{\max}$) and 2/3 maximal power output ($\frac{2}{3} W_{\max}$) (see Figure 2). Graphs T, E, Z do not necessarily correspond to mild, moderate, and severe states in this order.

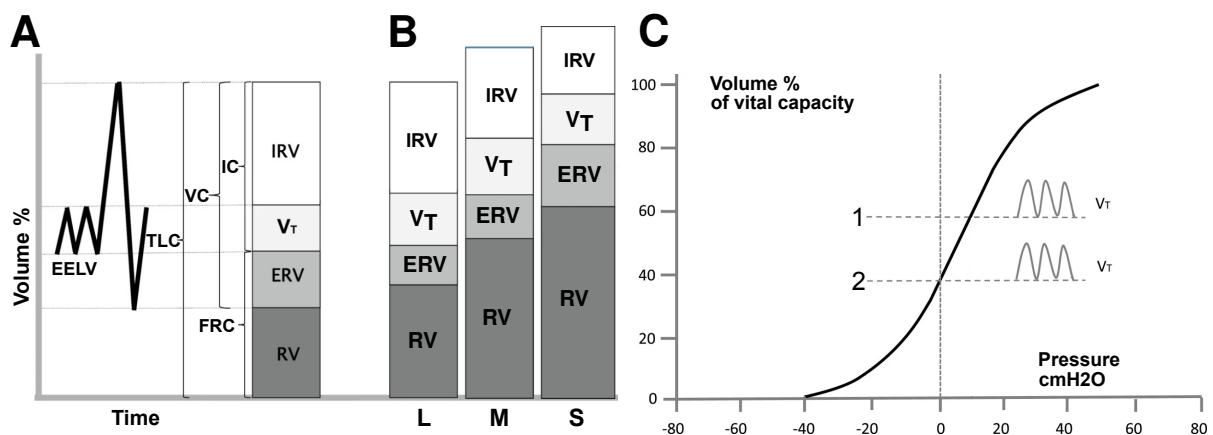


Figure 1. **A** ERV - expiratory reserve volume; FRC - functional residual capacity; IC - inspiratory capacity; IRV - inspiratory reserve volume; RV - residual volume; TLC - total lung capacity; VC - vital capacity; V_T - tidal volume. **B** Lung volume changes in mild (L), moderate (M), severe (S) COPD patients. **C** Pressure volume curve with EELV for two individuals (1 and 2).

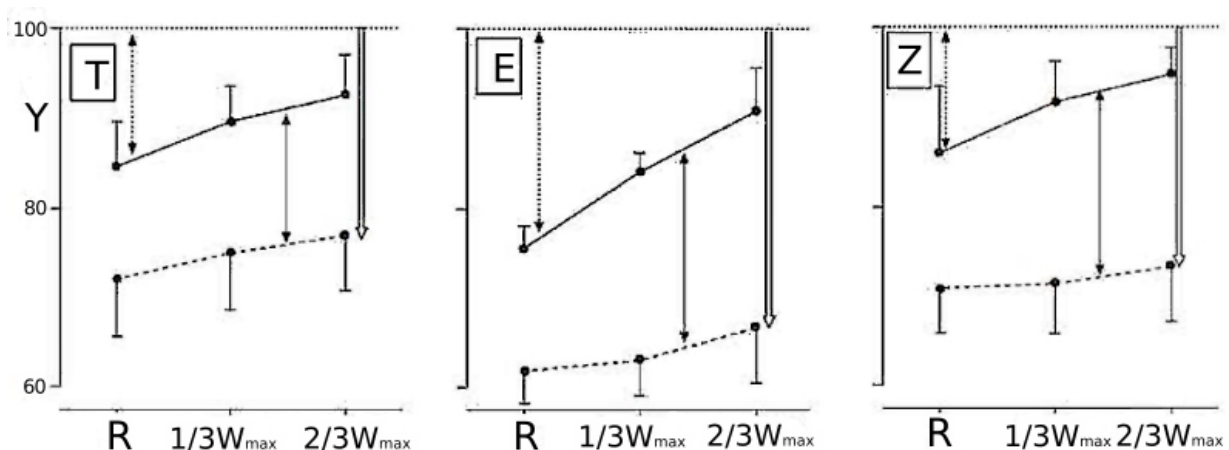


Figure 2. End-expiratory and end-inspiratory volumes. Arrows indicate different lung volumes. Y - Volume % TLC, R - at rest.

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

- A.** Inspiratory muscles of person 1 generate lower force than person 2.
- B.** In severe COPD compared to moderate, TLC does not increase, only the volume proportions of it change.
- C.** In Figure 2, panel T corresponds to mild, Z to moderate, and E to severe cases of COPD
- D.** According to Figure 1C, person 2 has higher RV than person 1.

46

Echiniscoides sigismundi, a marine tardigrade, can change its activity level and morphology when exposed to osmotic and chemical stress. To study that, a series of experiments that had different environmental conditions for tardigrades was conducted and their activity levels were measured. Each experiment consisted of three time periods (24 hours each) during which the environmental changes were applied (Figure 1, A-H).

Osmotic conditions used: ultrapure water ($\sim 0\%$), saturated seawater ($\sim 240\%$), and natural habitat seawater (Lsw). Chemicals used: DNP - a mitochondrial uncoupling agent. Note that in some cases osmotic and chemical conditions were applied together (e.g. DNP($\sim 240\%$) means DNP + saturated seawater).

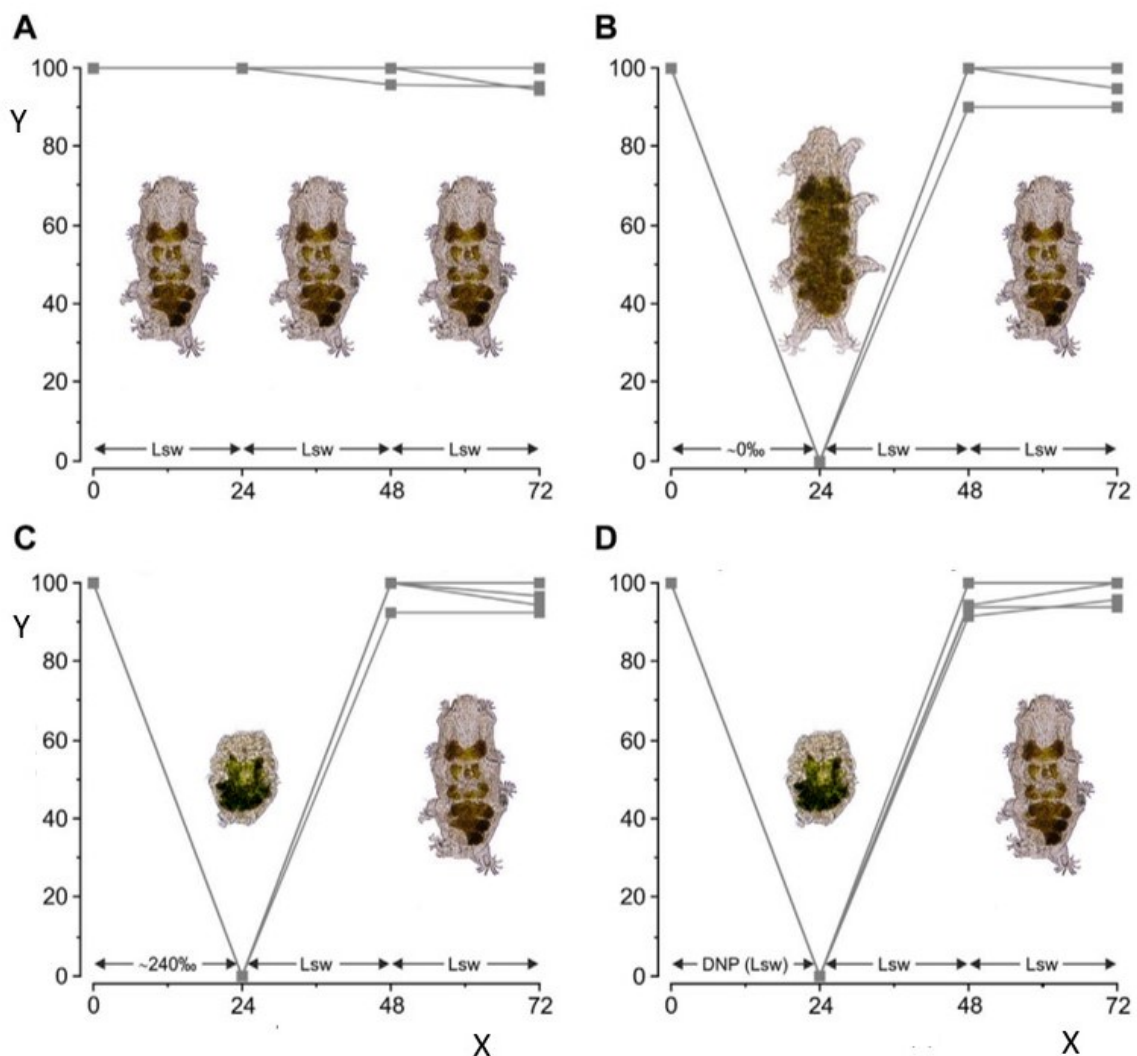


Figure 1. X- time (h), Y- Activity (%). All activity levels at $t = 72$ h in graphs B,C,D are not significantly different from A.

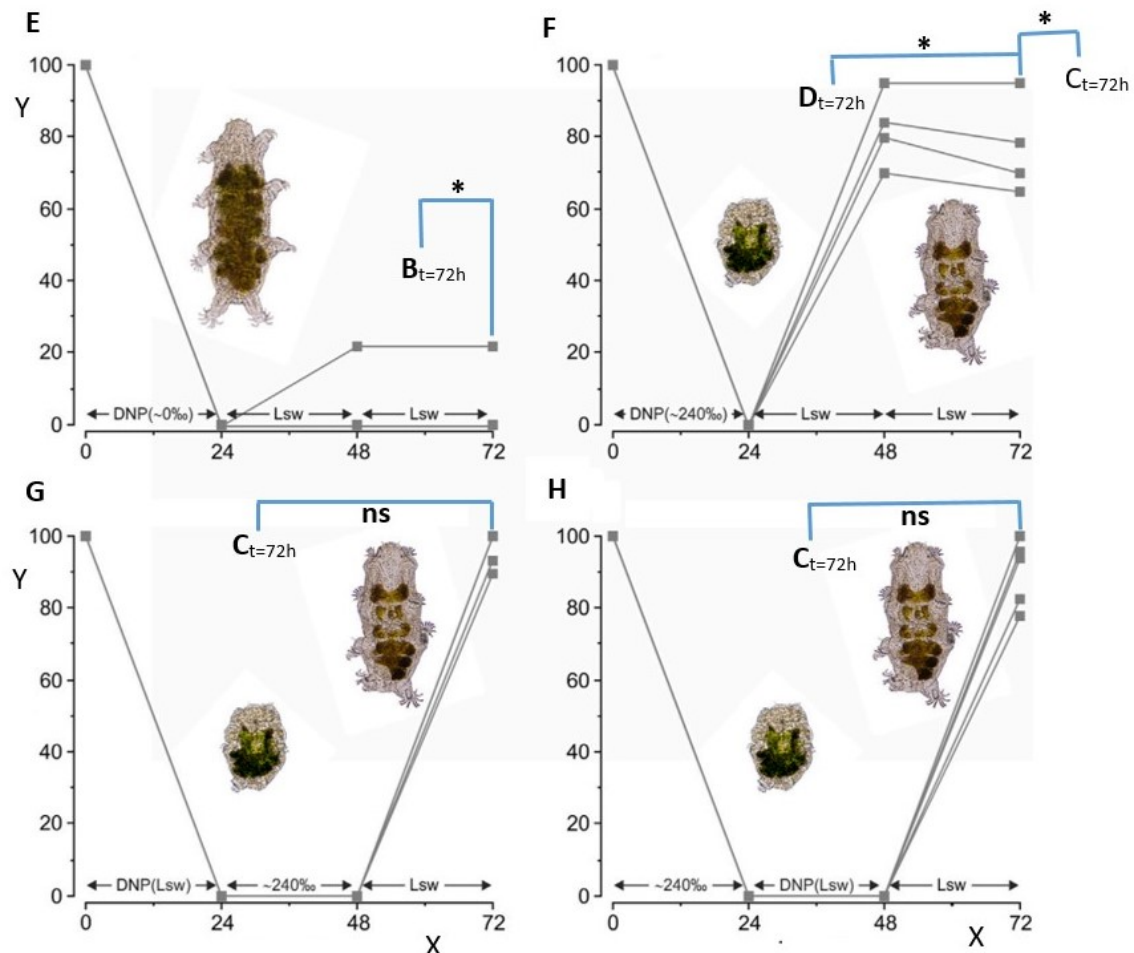


Figure 1. X- time (h), Y- Activity (%). **EFGH:** "*" - significantly different, "ns" - not significantly different from the given graphs (B,C,D) at t=72.

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

- A.** Chemical stress has a more pronounced impact on activity level compared to osmotic one.
- B.** ATP is crucial to tolerate hypoosmotic environments.
- C.** It is evident that DNP followed by either hypoosmotic or hyperosmotic conditions has the same impact on activity level at t=72h.
- D.** DNP exposure without osmotic stress is sufficient for a marine tardigrade's morphological changes to happen

47

Cancer immunotherapy is a cancer treatment approach where the body's immune cells attack tumor cells. During their development, tumor cells accumulate many neoantigens (new antigens). The more neoantigens present on the cell surface of tumor cells, the more efficiently immune cells destroy them. 'Immune checkpoint' is a term that defines the primary interaction between an immune cell and a tumor cell, and in which the immune cell 'decides' whether to attack the tumor cell or not.

However, tumor cells can avoid immune surveillance by hijacking the physiological pathway controlling T-cell activity (**Figure 1A**). To prevent the escape of tumor cells from immune attack, checkpoint inhibitors have been developed (**Figure 1A**).

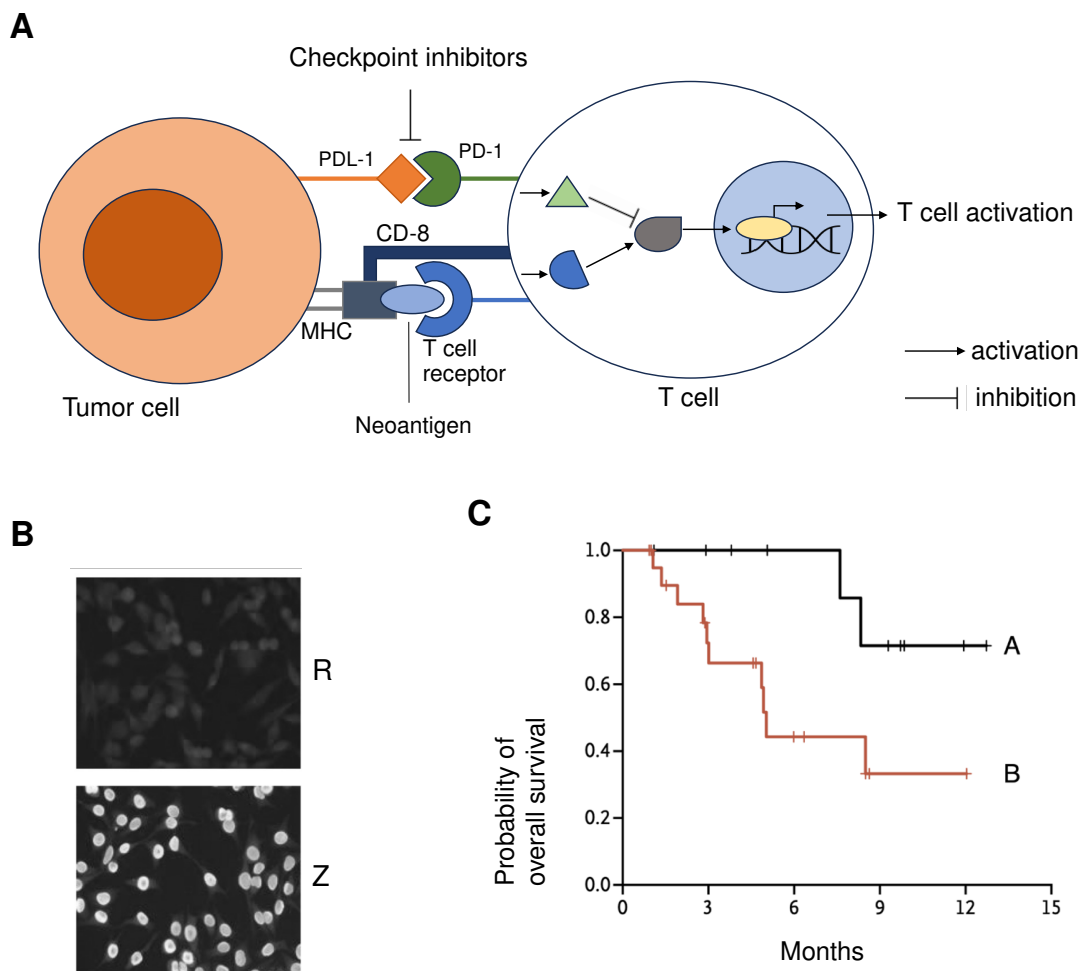


Figure 1. **A** The interaction between tumor and immune cells. **B** The serum of two cancer patients (R and Z) was applied to fixed human epithelial cells from a healthy donor. Next, cells were washed and stained with fluorescently labeled secondary antibodies against human immunoglobulins. Finally, cells were visualized by fluorescence microscopy. Note that immunotherapy should be avoided for one patient. **C** Clinical results of checkpoint inhibitor treatment on two cancer patient cohorts. Consider that the only significant difference between cohorts is the deficiency or proficiency of DNA mismatch repair.



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

- A.** Based on Figure 1, the main purpose of checkpoint inhibitors is to generate antibodies against tumor cells.
- B.** An antibody against PDL-1 of cancer cells can be a successful strategy in immunotherapy.
- C.** An oncologist is more likely to prescribe immunotherapy to Patient Z than to Patient R.
- D.** Most likely, cohort B has DNA mismatch repair-deficient tumors.

48

An mRNA vaccine is a type of vaccine where a pathogenic antigen is encoded in an mRNA sequence. Upon delivery to the human body, cells translate this mRNA and make protein antigens. Examples of mRNA vaccines include vaccines developed against the SARS-CoV-2 virus.

Before the development of mRNA vaccines, various forms of RNA nucleotide modifications had been tested for the immunogenic potential of mRNA itself (**Figure 1**). Note that under normal physiological conditions, RNA can exist outside cells in body fluids.

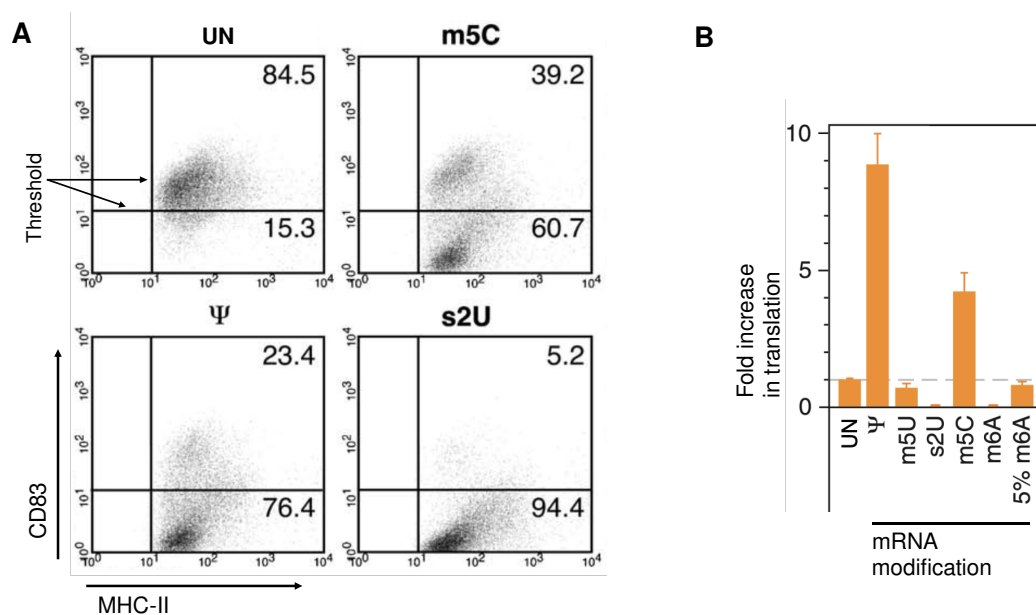


Figure 1. **A** Activatory response of antigen-presenting dendritic cells to specific RNA nucleotide modifications recorded in the cell surface receptor amounts (UN: unmodified). Each dot in each panel represents a single dendritic cell. Above the threshold, dendritic cells are activated by expressing higher levels of both cell surface receptors (CD83 and MHC-II). **B** Efficiency of modified mRNAs' translation by cells (UN: unmodified).

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

- A.** It is expected that the body's mRNA is modified to prevent auto-immune response.
- B.** mRNA vaccines having s2U modifications will have the highest efficiency in generating viral antigens.
- C.** mRNA vaccines against SARS-CoV-2 are more likely to contain m5C than pseudouridine (Ψ).
- D.** Both leukocytes and erythrocytes can serve as a host to produce antigens encoded in mRNA vaccines.

49

In fruit flies, dietary content affects arousal to mechanical vibrations during sleep, which is mediated by the enteroendocrine cells in the gut (**Figure 1**).

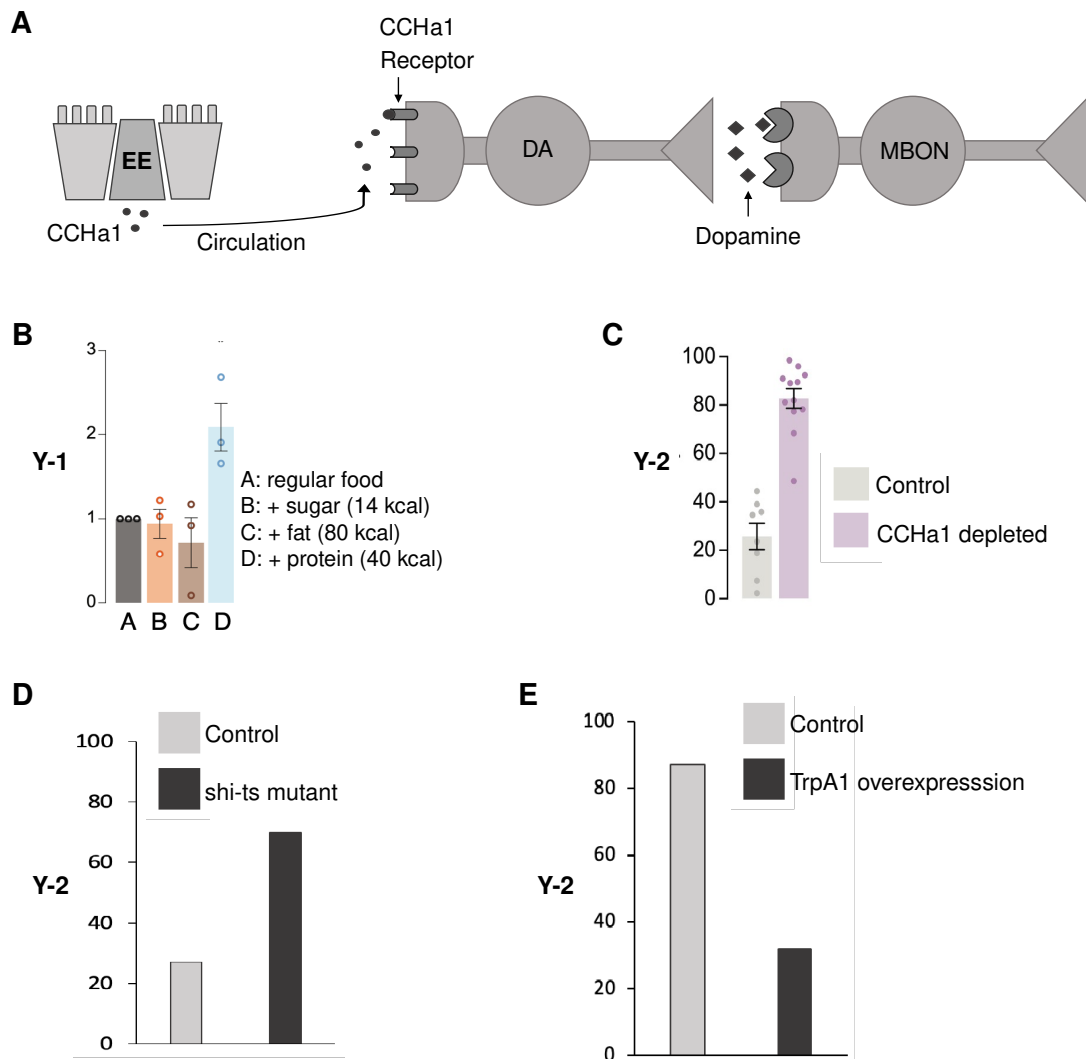


Figure 1. **A** The interaction scheme between enteroendocrine (EE) cells (secreting CCHa1) and the central nervous system. **B** The effect of dietary content on the expression of CCHa1 (Y-1: CCHa1 mRNA level in the gut). **C** The effect of CCHa1 depletion on arousal during sleep (Y-2: % flies awoken by stimulation). **D** The impact of shi-ts mutant, which results in defective endocytosis and exocytosis in the DA neuron, on arousal during sleep. **E** The impact of overexpression of TrpA1, a cation channel transporting Na^+ and Ca^{2+} , in MBON neurons on arousal during sleep. Concentrations of Na^+ and Ca^{2+} are lower inside the neuron than outside of it.

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

- A.** CCHa1 expression depends on the caloric content of the consumed food.
- B.** Results suggest that a protein-rich diet reduces sleep arousal.
- C.** CCHa1 should result in the excitation of DA neurons to prevent arousal during sleep.
- D.** The synapse between DA and MBON neurons should be inhibitory to prevent arousal during sleep.

50

During *Drosophila* development, oogenesis establishes the body plan before fertilization.

The concentration gradient of the bicoid mRNA in the oocyte determines the anterior-posterior axis (Figure 1A), a process controlled by the Exuperantia protein. Exuperantia anchors bicoid mRNA at the anterior end of the oocyte, thereby preventing its free diffusion and subsequently altering the distribution of bicoid protein in the developing embryo (Figure 1B).

The concentration gradient of the gurken protein (Figure 1C) and its positive interaction with the torpedo protein is critical for determining the dorsoventral axis of the embryo. Interestingly, a wild-type oocyte inside a torpedo-deficient follicle develops into an entirely ventral embryo, while a torpedo-deficient oocyte inside a wild-type follicle develops a normal body plan.

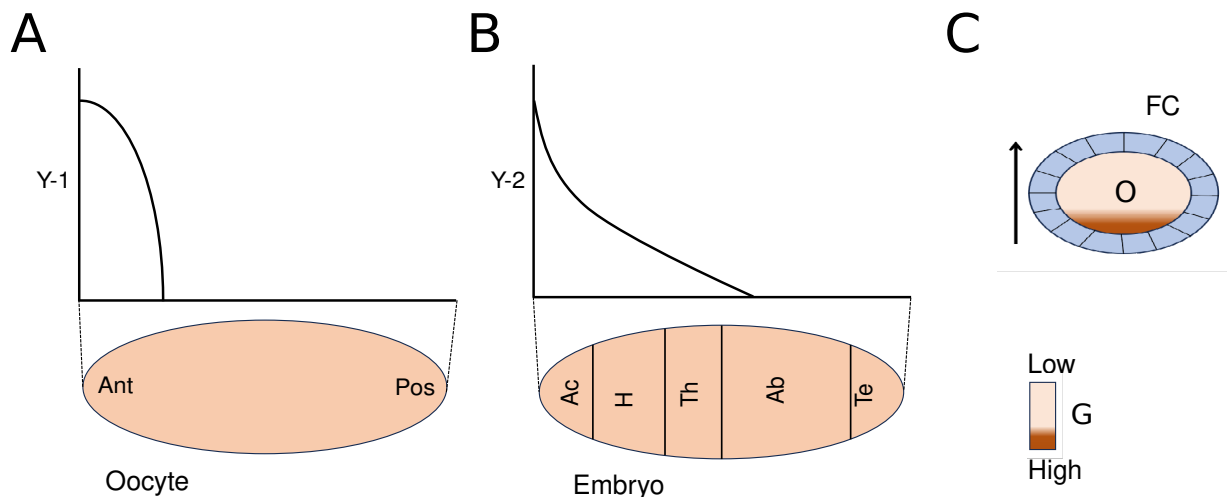


Figure 1. **A** Y-1: Bicoid mRNA concentration, Ant: Anterior, Pos: Posterior. **B** Y-2: Bicoid protein concentration, Ac: Acron, H: Head, Th: Thorax, Ab: Abdomen, Te: Telson. **C** O: oocyte, FC: follicle cells, G: Concentration gradient of gurken.

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

- A.** You can deplete bicoid in male testes to get mutant embryos lacking head and thorax regions.
- B.** An Exuperantia loss-of-function mutant embryo will have an extended acron.
- C.** Torpedo gene expression is not required in oocytes for establishing the normal dorsal-ventral axis.
- D.** The arrow in Figure 1C points from the dorsal to the ventral part of the future embryo.

Exam B

Biosystematics

Task #1

- . **FALSE.** For the given tree all of the final taxonomic points are located at the last level. So, for all of the organisms the determination process will take no more than 9 steps.
- . **TRUE.** $2^0 + 2^1 + 2^2 \dots + 2^9 = 512$
- . **TRUE.** There are 128 possible taxonomic outcomes for an organism being observed at level 3 and 32 possible outcomes at level 5. Since $128/32=4$, there are four times more possible outcomes at level 3 than at level 5.
- . **FALSE.** No link between the key and phylogeny.

Reference: https://en.wikipedia.org/wiki/Single-access_key

Task #2

- . **TRUE.** The number 89 on the branch leading to the Cervus samples indicates that in 89 out of 100 iterations, Dama dama was the sister taxon to Cervus.
- . **FALSE.** Mitochondrial DNA, which frequently mutates, is better suited for analyzing site changes among individuals of one species than histone genes, which are known for their conservativeness.
- . **FALSE.** The most weakly supported branch would be the one with bootstrap value of 50 and sample 163 is not part of it.
- . **FALSE.** There might be several less likely branching patterns with cumulative occurrence = 50%.

Reference:

Phylogeography of Red Deer (*Cervus elaphus*): Analysis of MtDNA Cytochrome b Polymorphism M. V. Kuznetsova, A. A. Danilkin, and M. V. Kholodova

Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, pr. Leninskij 33, Moscow, 119071 Russia email: mkarja@mail.ru. Received November 10, 2011.

Photo from the website of the Kolsai Lakes National Nature Park «Көлсай көлдері» (<https://kolsai-koldery.kz/science/fauna/?id=29>)

Cell and Molecular Biology

Task #3

- . TRUE. . There is cycle dependence of BRCA1 protein concentration, which regulates the choice of DSB repair pathway
- . TRUE. . BRCA1 deficient cells have deficient HR repair. To maintain cell survival cancer cells increase reliance on the NHEJ pathway for DNA repair.
- . FALSE. . According to Figure 2, in normal cells BRCA1 concentration is lower in G1 compared to G2, meaning that HR repair activity is lower too
- . TRUE. . BRCA1 deficient cells are NHEJ proficient, and since there is no inhibitor of 53BP1, there is no cell cycle dependence of NHEJ repair. 53BP1 deficient cells are NHEJ deficient and rely on HR for DSB repair. However, since BRCA1 levels are lower in G1 phase, there will be little to no repair of breaks upon treatment of drugs blocking G1/S transition.

Reference:

<https://jhoonline.biomedcentral.com/articles/10.1186/s13045-020-00956-5>
<https://www.nature.com/articles/s41467-021-21544-2>

Task #4

- . **TRUE.** The cells are in a high potassium buffer and they should be depolarized
- . **FALSE.** They are activated by depolarization with High potassium, so, they are voltage gated channels, not ligand-gated

- . **FALSE.** They are activated by depolarization with High potassium, so, they are voltage gated channels, not ligand-gated
- . C. Replacing 30mM potassium with high glucose can potentially influence cytosolic calcium levels by altering the activity of voltage-gated calcium channels (VGCCs), ATP-dependent calcium pumps (such as the plasma membrane Ca^{2+} -ATPase), and intracellular calcium release channels (e.g., IP_3 receptors). It can be deduced from the part where we explain the effect of calcium in beta cells. Calcium activates Krebs cycle enzymes (isocitrate dehydrogenase, alpha-ketoglutarate dehydrogenase), enhancing ATP production. This all is done when glucose is present and are parts of aerobic respiration. So, the calcium concentration will increase, after stimulation with high glucose.
- . **FALSE.** Intracellular calcium is mainly (ex from ER) used for the regulation of cellular processes. so, blocking of L-type calcium channels by isradipine, will not decrease mitochondrial calcium levels activated by high glucose.

Reference:

Glycogen Synthase Kinase 3 Beta Controls Presenilin-1-Mediated Endoplasmic Reticulum Ca^{2+} Leak Directed to Mitochondria in Pancreatic Islets and β -Cells

Christiane Klec, Cell Physiol Biochem. Author manuscript; available in PMC 2019 April 11

Task #5

- . **TRUE.** The following reaction is facilitated by the ketogenic diet because it depletes stores of oxaloacetate: Aspartate + alpha-ketoglutarate $\rightarrow$ glutamate + oxaloacetate. As a result, glutamate is produced.
- . **FALSE.** Mutated enzyme increases the activity of the Krebs cycle, thus increasing the use of oxaloacetate, which in turn increases the production of GABA according to what was said in A. Figure 2 shows us that there is some relation between catecholamines and ketogenic diet, and we can conclude that the mutation will increase make the organism more resistant to seizures (that is increase the latency)

- . **TRUE.** L-DOPA is a precursor of dopamine. Adrenaline/noradrenaline (unclear exactly which one of them, from the given information), produced from dopamine were found to be an effective anti-convulsant. Administration of dopamine, the production of which is usually reduced in Parkinson's disease, in the form of L-DOPA is an efficient form of PD treatment.
- . **FALSE.** There is a lack of information on whether the lack of efficacy of ketogenic diet is due to the lack of noradrenaline or adrenaline

Reference:

Masino, S. A., & Rho, J. M. (2012). Mechanisms of ketogenic diet action. Jasper's Basic Mechanisms of the Epilepsies - NCBI Bookshelf. <https://www.ncbi.nlm.nih.gov/books/NBK98219/>

Szot, P. (2004). The role of norepinephrine in the anticonvulsant mechanism of action of the ketogenic diet. In Humana Press eBooks (pp. 265–278). https://doi.org/10.1007/978-1-59259-808-3_20

Task #6

- . **TRUE.** Binding of the cis-trigger to the toehold switch makes RBS available for the translation initiation.
- . **TRUE.** Translation of truncated mRNAs will use up cellular resources to produce defective proteins. In addition, stop codon deficient mRNAs will trap ribosomes decreasing the ribosome-recycling efficiency.
- . **TRUE.** This system is only useful for the expression of GOI in prokaryotic cells because there is no spatiotemporal separation of transcription and translation. In eukaryotes, pre-mRNA modifications, such as attachment of 5' cap and polyadenylation, facilitate the export of only mature mRNA from the nucleus.
- . **TRUE.** As long as trigger RNA, or any oligonucleotide sequence with complementary sequence, can bind to the toehold switch, it will unbind the hairpin structure, making RBS available for the translation initiation.

Reference

<https://doi.org/10.1038/s41589-021-00736-3>

Task #7

- . **TRUE.** In panel A, only one side of the CldU (red) is elongated by IdU (green), indicating replication progression from a single fork. In panel B both sides are elongated by IdU (green), indicating replication progression from two forks.
- . **TRUE.** Since the direction of replication is from CldU (red) to IdU (green) panel C shows the merging of two replication forks, which results in replication termination. In panel E DNA is not labeled with IdU after CldU labeling, which indicates either replication fork collapse or replication termination.
- . **FALSE.** Since panel B represents bidirectional replication from a single origin, CldU has to be incorporated into both leading and lagging strands of DNA (if the right side of the replication origin is leading, the other must be lagging).
- . **FALSE.** In panel F, there are two CldU (red) tracks, indicating the presence of two origins of replication. Bacterial DNA is replicated using a single origin of replication. Therefore, the DNA cannot belong to a bacterial species.

Reference:

Halliwel, J. A., Gravells, P., & Bryant, H. E. (2020). DNA fiber assay for the analysis of DNA replication progression in human pluripotent stem cells. *Current Protocols in Stem Cell Biology*, 54, e115.

Task #8

- . **FALSE.** From reaction 2, we notice that both DNA strands were cleaved, suggesting that the enzyme is an endonuclease. However, we can see two distinct bands, indicating that the enzyme does not generate blunt-ended breaks, rather it makes 5'-overhang DNA breaks.
- . **TRUE.** From reaction 3, we see that only the green strand is degraded (indicated by the smeared band), suggesting that the enzyme is an exonuclease. Since the upper green strand is being digested and the 5'-end is chemically inert, exonuclease must have a 3'-5' polarity.

- . **TRUE.** For reactions 4 and 5, we observe an extension of the products from reactions 2 and 3, respectively (the green strand has a free 3'-end, which is extended to the same length as the red strand). Extension of DNA (or DNA lengthening) is mediated by DNA polymerases.
- . **FALSE.** DNA polymerase will extend the 3'-end of the green strand of the original substrate, resulting in 100 bp double-stranded DNA as in reaction 5.

Reference:

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 #9

- . **FALSE.** Under normal conditions (without compound X treatment), the majority of cells are in the G1 phase of the cell cycle, represented by the $2n$ DNA content. $4n$ DNA content corresponds to the G2 and M phases, while cells having DNA content between $2n$ and $4n$ correspond to the S phase.
- . **TRUE.** We can see from the data that under compound X treatment, some cells have $8n$ DNA content, an integer multiple of the $2n$ chromosome set. Therefore, compound X causes a polyploidy.
- . **FALSE.** Cells deficient for checkpoint kinases A and B do not show any difference when treated with compound X. Therefore, the effect of compound X depends on the presence of checkpoint kinases A and B.
- . **FALSE.** Upon treatment with compound X (which causes DNA damage), cells having intact protein kinases A and B have $8n$ DNA content (tetraploid), suggesting protein kinases promote more than one round of DNA replication within one cell division.

References:

1. T. Davoli, E. Lazzerini Denchi, T. de Lange (2010) Persistent Telomere Damage Induces Bypass of Mitosis and Tetraploidy. Cell 141: 81-93.

Task #10.

- . **TRUE.** Transcription and translation are much more energy-costly than simple protein phosphorylation/dephosphorylation. Therefore, for quick cellular response regulation of activity of protein B is more energy-efficient than that of protein A.
- . **FALSE.** The presence of Histone H3 and the absence of Actin indicates that Fraction II represents DNA-bound proteins. In Fraction II, Ligand L increases the amount of transcription factor X. Therefore, Ligand L increases the affinity of Transcription Factor X to the DNA.
- . **TRUE.** The deficiency of kinase increases the abundance of the differentiation marker. Therefore, phosphorylation prevents the interaction (dimerization) between proteins A and B, which is necessary for stem cell differentiation.
- . **TRUE.** Based on the structures, aspartate is the most likely candidate to mimic phosphorylated serine. Mutating serine to aspartate mimics constitutive phosphorylation. Therefore, Mutating the serine-121 residue in protein B to aspartate likely causes the same effect on the formation of heterodimers as the activity of the kinase.

References:

1. Campbell biology, 10th edition, Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson (2014), Pearson
2. <https://en.wikipedia.org/wiki/Phosphomimetics#>

Task #11

- . **FALSE.** Cycloheximide blocks translation elongation, thereby protein synthesis. Monitoring the abundance of proteins over time under cycloheximide treatment provides information about protein degradation only.
- . **TRUE.** Figure 1 shows that protein B's abundance decreases faster than protein C's. Therefore, protein B's half-life is shorter than protein C's.

- . **TRUE.** Assuming protein A's half-life is shorter than protein C's, protein A should degrade faster. However, Figure 1 shows that protein A is stable under cycloheximide treatment, suggesting that cycloheximide does not affect the synthesis of protein A. The text states that cycloheximide affects eukaryotic translation elongation. The only non-eukaryotic ribosomes in human cells are inside mitochondria (due to endosymbiotic theory, it is believed that mitochondria originated from prokaryotic cells). Therefore, protein A must be a mitochondrial protein.
- . **FALSE.** From Figure 2, we conclude that proteasomes are responsible for degrading protein B, while lysosomes are responsible for degrading protein C. Since proteasomes are multiprotein complexes residing in the cytoplasm, it is relatively unlikely that proteasomes degrade extracellular proteins. On the other hand, lysosomes can receive extracellular proteins through endocytosis, such as during phagocytosis, when endocytotic vesicles fuse with lysosomes for digestion. Therefore, protein C is more likely to be extracellular than protein

Reference:

Campbell biology, 10th edition, Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson (2014), Pearson
<https://en.wikipedia.org/wiki/Cycloheximide>
<https://www.thermofisher.com/kr/ko/home/life-science/cell-analysis/cell-analysis-learning-center/protein-degradation-resource-center/mechanisms-protein-degradation.html>

Task #12

- . **FALSE.** The FRET efficiency depends on the distance between the donor and the acceptor. Increasing the concentration of donor and acceptor should reduce the average distance between molecules in a solution. Therefore, the FRET efficiency increases if the concentration of both donor and acceptor in a solution is changed from 10 nM to 20 nM.
- . **FALSE.** For an efficient FRET, the emission spectra of the donor must overlap with the excitation spectra of the acceptor. The emission spectra of the donor (G8) do not overlap with the excitation spectra of Brim43.

However, the opposite is true, emission spectra of Brim43 overlap with excitation spectra of G8.

- . **TRUE.** Incubation of CFP-YFP fusion with the protease should decrease the FRET (CFP and YFP will be separated). Protease P3 decreases FRET the most; therefore, protease P3 has the highest activity among tested proteases.
- . **TRUE.** For inhibitor Z, FRET depends on the substrate (CFP-YFP) concentration added to the reaction (the higher the substrate, the lower the FRET) suggesting Z is a competitive inhibitor. On the other hand, for inhibitor Q, FRET is always high (no cleavage between CFP and YFP), suggesting inhibitor Q non-competitive inhibitor.

References:

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

<https://www.bmglabtech.com/en/fluorescence-intensity/>

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 #13

- . **FALSE.** The structure shown in Figure 1b generates a substrate for nucleases involved in cross-over formation in meiosis (the chiasmata).
- . **TRUE.** In the absence of factor X, telomeres of different chromosomes are ligated together, suggesting that factor X is the subunit of the shelterin complex. In the absence of Factor Y, there is no difference in chromosomes. However, when both factors are absent, telomere fusion events, promoted by the absence of Factor X alone, are now reverted, suggesting that Factor Y is involved in telomere-to-telomere fusion or DNA break repair. Therefore, Factor Y is more likely to be the DNA break repair factor than Factor X.
- . **TRUE.** Since the chromosome is being pulled to opposite poles of the cell, it should have two kinetochore attachment points, hence two centromeres.
- . **FALSE.** The chromosomal bridge breaks during telophase (when chromosomes start decondensation). During telophase, there is no spindle movement.

References:

Rhee, David Beomjin, "Characterizing the Role of DNA Repair Proteins in Telomere Length Regulation and Maintenance: Fanconi Anemia Complementation Group C Protein and 8-Oxoguanine DNA Glycosylase." PhD diss., University of Tennessee, 2010.
https://trace.tennessee.edu/utk_graddiss/843

Denchi, E., de Lange, T. Protection of telomeres through independent control of ATM and ATR by TRF2 and POT1. *Nature* 448, 1068–1071 (2007).
<https://doi.org/10.1038/nature06065>

Maciejowski et al., Chromothripsis and Kataegis Induced by Telomere Crisis. 2015, *Cell* 163, 1641-1654 <http://dx.doi.org/10.1016/j.cell.2015.11.054>

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

Ecology

Task #14

- . **FALSE.** For the purpose of restoring and enhancing the biota, the introduced organisms must align correctly with their food chain. The key components include phytoplankton (producers), zooplankton, fish, and benthic organisms. It's crucial to note that fish, positioned at the top trophic levels, shouldn't feed directly on phytoplankton. Doing so could lead to unnecessary losses in phytoplankton, impacting zooplankton levels and ultimately contributing to the decline of fish populations.
- . **TRUE.** In Figure 2, you can see how newly emerged adults of species "Z" appeared when the salt level was higher than when species "W" began to emerge.
- . **TRUE.** Considering the data indicating that the Syr Darya supplies more water than the Amu Darya, and referring to Figure 2, it can be inferred that the Northern Aral Sea has lower salinity compared to the Southern part. Furthermore, based on Figure 2, the cause of death for species "W" is attributed to high salt levels. By connecting this information, one can

conclude that newly observed species "W" individuals have emerged in the Northern Aral Sea.

- . **FALSE.** From Figure 2, you can see that after adding new animals to the environment, the number of individuals of species "Z" began to decrease, which suggests that among the imported animals there were predators or competitors of species "Z", but not its prey.

References:

Photo of the Aral Sea: Авторство: NASA. Collage by Producercunningham..
1989: aral sea 1989 250mFile:Aralsea tmo 2014231 lrg.jpg,
<https://commons.wikimedia.org/w/index.php?curid=35813435>
<https://doi.org/10.1007/978-3-030-42254-7>

Task #15

- . **TRUE.** If we set the equation in Figure 1 equal to 0 (due to the stable population size), we arrive at an equation resembling a straight line, specifically $N_1 = K_1 - \alpha N_2$. Assuming N_1 corresponds to the x-axis as indicated by the graph, setting N_1 to 0 yields $N_2 = K_1/\alpha$, representing the intersection with the y-axis.
- . **TRUE.** Upon thorough examination of the equations, it becomes evident that the carrying capacity is decreased by two factors: the product of the number of individuals of another species and a competition coefficient (αN_2), and the number of individuals of the same species (N_1). This implies that the carrying capacity of species 1 is influenced by both N_1 and N_2 , indicating the consideration of intraspecific competition within the equation. (the same is for species 2)
- . **TRUE.** Substituting the values for the equations of the lines for two species ($N_1 = K_1 - \alpha N_2$, $N_2 = K_2 - \beta N_1$) reveals that the constructed lines do not intersect, indicating the eventual extinction of one species. Among the two combinations without intersection, the populations will belong to the one where the line representing species 1 is positioned above the line representing species 2. The initial population values will lie between these lines and will tend towards the x-axis over time,

signifying that the y value will approach 0. As the y-axis represents the number of deer (N_2), this implies that deer will ultimately face extinction.

- **FALSE.** From Figure 2, it's apparent that only in one out of four cases do all points converge at the intersection of lines, indicating a state where both species can coexist in equilibrium. In the other cases, one of the species inevitably becomes extinct.

References:

https://bio.libretexts.org/Courses/Gettysburg_College/01%3A_Ecology_f or_All/15%3A_Competition/15.05%3A_Quantifying_Competition_Using_the_Lotka-Volterra_Model

Task #16

- **FALSE.** Fast-growing “colonizing” plants benefit at most on rich soils because fast growth requires massive and immediate mobilization of nutrients. Adding a new limiting factor (poor soil) creates a new dimension for long-term competitors.
- **TRUE.** Reducing the *Stipa* biomass would add the growth limiting factors allowing creating a new niche dimension.
- **FALSE.** The loss of the limiting factor (hard soil with turf) by plowing would eliminate the niche dimension and favour the subsequent *Stipa* overgrowth on the newly plowed territories.
- **TRUE.** More adapted to droughts, tall *stipa* plants can shadow the short turf plants.

References:

- http://tbe.elte.hu/olms/TBE_OLM7.1.pdf
- <https://www.nature.com/articles/nature13144#Abs3>
- <https://www.nature.com/articles/nature05684#Abs3>
- <https://pubmed.ncbi.nlm.nih.gov/27556951/>
- <https://pubmed.ncbi.nlm.nih.gov/20963609/#:~:text=The%20niche%20dimension%20hypothesis%20predicts,tradeoffs%20for%20different%20limiting%20factors.>

· Larin I. V., Larina V. K. Fodder plants of hayfields and pastures of the USSR : in 3 volumes / edited by I. V. Larin. — M. ; L. : Selkhozgiz, 1950. — Vol. 1 : Spore, gymnosperm and monocotyledonous. — pp. 248-252. — 689 p.

Task #17

- . **TRUE.** Long-living males infected with Wolbachia parasites can spread the parasite across a larger number of females, which in turn increases occurrence of embryonic death as a result of cytoplasmic incompatibility.
- . **TRUE.** If the power of a primary irradiation was decreased, a certain number of fertile females infected with Wolbachia might enter the population with males. As a result, their progeny will not undergo embryonic death, which will lead to spreading of this particular Wolbachia strain, and hence population replacement.
- . **FALSE.** There are four types of mating:
 - WT female - WT male - WT progeny
 - Wolbachia female - WT male - Wolbachia progeny
 - Wolbachia female - Wolbachia male - Wolbachia progeny
 - WT female - Wolbachia male - embryonic death as a result of cytoplasmic incompatibility
- . **TRUE.** . There is some gradient in the distribution of hatched eggs (more eggs in the area closer to the control site and vice versa), and with this visible, mosquito migration is and suitable.

Reference:

Baton, L. A., Zhang, D., Li, Y., & Xi, Z. (2021). Combining the incompatible and sterile insect techniques for pest and vector control. In CRC Press eBooks (pp. 367–404). <https://doi.org/10.1201/9781003169239-20>

Task #18

- . **FALSE.** Based on Figure 1, you notice that in invaded areas (where big-headed ants exterminate acacia ants), megaherbivores destroy more whistling thorn trees, suggesting that the interaction between whistling thorn trees and acacia ants is mutualism (both benefit from the interaction).
- . **FALSE.** . Figure 1 shows that big-headed ant-invaded areas are more visible, while Figure 2 shows that the probability of zebra kill occurrence is lower under higher visibility, suggesting zebras are less vulnerable to lion predation in big-headed ant-invaded areas.
- . **FALSE.** . Between 2000 and 2020, the number of big-headed ants increased, which based on Figure 1, suggests that the areal coverage of whistling trees decreased between 2000 and 2020. On the other hand, Figure 2 shows that fewer zebras are killed in areas covered with less whistling thorn trees. Therefore, between 2000 and 2020, lions are expected to shift their prey from zebras to buffalos, not from buffalos to zebras.
- . **TRUE.** . Based on Figure 2, the lower the visibility in the region, the fewer zebras are killed, suggesting lions prefer ambushing zebras under lower visibility (for zebras) than chasing them under higher visibility.

References:

1. Kamaru, D.N. et al. Disruption of an ant-plant mutualism shapes interactions between lions and their primary prey. Science 383, 433-438 (2024)
2. Campbell biology, 10th edition, Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson (2014), Pearson

Ethology

Task #19

- . **FALSE.** . As is seen from Figure 1B, Vv body weight ~ 280mg, venom ~5.2mg, thus by proportion $(5.2 \times 100) / 280 = 1.9$ mg, which is far less than the stated range of 2.6-2.8%.
- . **FALSE.** . This mutation mimics the control group in Figure 1a, and it is evident that heating alone decreases survival.
- . **FALSE.** . The sham sting group shows that only heating is not as efficient as both being stung and heated.
- . **FALSE.** . As it is seen from Figure 1a, at 44 °C, the hornet's survival is the same regardless of the attacking species

Reference:

Gu, G., Meng, Y., Tan, K., Dong, S., & Nieh, J. C. (2021). Lethality of honey bee stings to heavily armored hornets. *Biology*, 10(6), 484.

Task #20

- . **FALSE.** . As it is seen directly from the graph a (easy option)
- . **TRUE.** . Females are on average heavier, then we can conclude from graph B that the heavier male on average wins more often. (moderate option)
- . **FALSE.** . To use copulation duration as an indicator of mating cost, one should first confirm that indeed more sperm is transferred for a longer copulation duration. (moderate option)
- . **TRUE.** . From the graph, we conclude that in type1 behavior, male choosiness is very high, which means males are the ones who select for mating, and since assumed females are small-sized they will not be selected for mating and there will be negative sexual selection upon them. (Hard option)

References:

For graphs I and II modified from - Kuriwada, T. (2022). Encounter with heavier females changes courtship and fighting efforts of male field crickets *Gryllus bimaculatus* (Orthoptera: Gryllidae). *Journal of Ethology*, 40(2), 145-151.

For graph III modified from - Bonduriansky, R. (2001). The evolution of male mate choice in insects: a synthesis of ideas and evidence. *Biological Reviews*, 76(3), 305-339.

Image of *Gryllus bimaculatus* — [African.field.cricket.org](https://www.africanfieldcricket.org/) - *Gryllus bimaculatus* - Wikipedia

Task #21

- . **TRUE**. . Derived from the equation. $0.43 = 1 - (\text{prey size}) / (\text{predator size}) \rightarrow 0.57 = (\text{prey size}) / (\text{predator size}) \rightarrow 0.57 / 1 = (\text{prey size}) / (\text{predator size}) \rightarrow$ just flip the numerator and denominator $\rightarrow 1.75$
- . **FALSE**. . As it is seen from the Figure 1 a and b, body size difference in females should be several times higher than body size difference in males, thus males are more aggressive and cannibalize easily 75
- . **FALSE**. . Because in conditions of hunger crabs are expected to eat the most injured ones, so the more legs are lost, the higher probability that this crab dies and is not seen as injured crab (due to survival bias). So in real life, the level of injury of surviving crabs will decrease as the number of lost legs increases.
- . **TRUE**. . It is directly seen from the graph 1c

References:

Reference : all graphs were adopted and some modified from Zhang, Z., Yokota, M., & Strüssmann, C. A. (2018). Cannibalism in the Japanese mitten crab, *Eriocheir japonica*. *Hydrobiologia*, 807, 367-376.

Genetics & Evolution

Task #22.

- . **FALSE.** In normal/healthy gestation both genes are active despite the sex of a baby.
- . **FALSE.** Paternal disomy of the chromosome 11 implicates bi-allelic overexpression of IGF2 gene resulting in anomalous proliferation.
- . **TRUE.** Igf2r mutations are associated with overgrowth and embryonic death, but both phenotypes are rescued in an Igf2 null background.
- . **TRUE.** Monogamous species do not exhibit intersexual competition because the reproductive success stems from the cooperation of sexes.

References:

- <https://www.lidsen.com/journals/genetics/genetics-03-04-096>
- <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3994769/>

Task #23

- . **FALSE.** Colonial yeasts, being denser than the original yeasts, exhibit a tendency to settle more readily.
- . **TRUE.** Figure 3 indicates that the strain 8, a mutated haploid, has a deletion of one adenine, resulting in a frameshift. Figure 2a demonstrates that all crosses between wild-type and mutated strains resulted in wild-type (single-celled) offspring, thus, showing a recessive inheritance.
- . **TRUE.** The sequencing aligns with a heterozygous diploid strain exhibiting sequences similar to str 1 and str 8.
- . **TRUE.** CTS1 levels are decreased in mutated strains. As we can see from the figure1, the colonies are formed because of the incomplete cell wall destruction between the mother and daughter cells. Hence, it is possible that the product of CTS1 is involved in the final stages of the cell cycle (where cell wall destruction occurs), rather than the initial stages of the cell cycle.

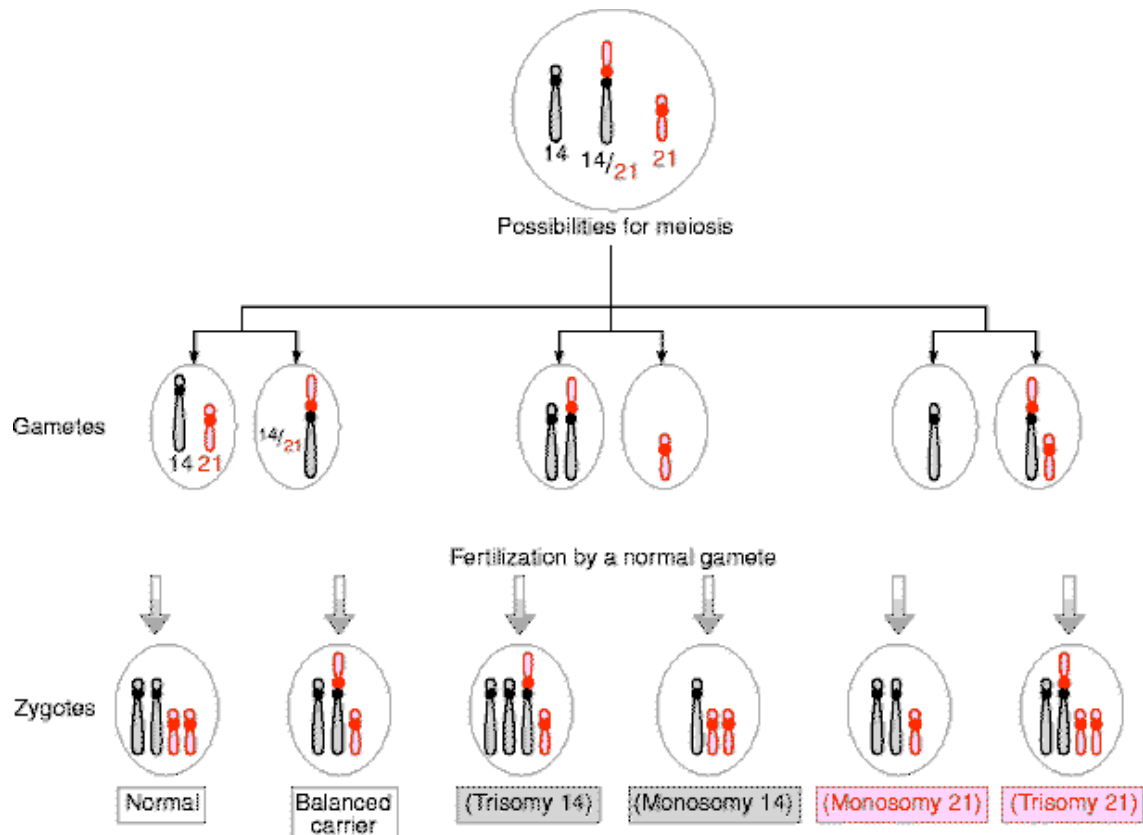
References:

Rodrigues-Prause A, Sampaio NMV, Gurol TM, Aguirre GM, Sedam HNC, Chapman MJ, Malc EP, Ajith VP, Chakraborty P, Tizei PA, Pereira GAG, Mieczkowski PA, Nishant KT, Argueso JL. A Case Study of Genomic Instability in an Industrial Strain of *Saccharomyces cerevisiae*. *G3* (Bethesda). 2018 Nov 6;8(11):3703-3713. doi: 10.1534/g3.118.200446. PMID: 30254181; PMCID: PMC6222563.

Oud B, Guadalupe-Medina V, Nijkamp JF, de Ridder D, Pronk JT, van Maris AJ, Daran JM. Genome duplication and mutations in *ACE2* cause multicellular, fast-sedimenting phenotypes in evolved *Saccharomyces cerevisiae*. *Proc Natl Acad Sci U S A*. 2013 Nov 5;110(45):E4223-31. doi: 10.1073/pnas.1305949110. Epub 2013 Oct 21. PMID: 24145419; PMCID: PMC3831460.

Task #24

- . **FALSE.** Robertsonian translocation occurs only with acrocentric chromosomes. Chromosomes 1 and 2 are metacentric.
- . **TRUE.** Non-lethal zygotes: Normal, Balanced carrier, Trisomy 21, which is 3 out of 6 = 50% (picture).
- . **TRUE.** The absence of the 21st chromosome in the patient may result from either non-disjunction of chromosomes during meiosis or being a carrier of the Robertsonian translocation. Determining whether the latter is the case can be done by examining the diploid karyotype for the presence of a translocation.
- . **TRUE.** Figure 2 allows for the counting of acrocentric chromosomes, with chromosomes 14 and 21 being definitively acrocentric. Therefore, if a person possesses only 5 acrocentric chromosomes (13, 14, 15, 21, 22), they can potentially form 5 homologous and 10 heterologous translocations.



References:

By Original from DataBase Center for Life Science (DBCLS) Derivative by Mikael Häggström, M.D. Author info- Reusing images- Conflicts of interest: None Mikael Häggström, M.D. - File:202208 Chromosomal structural abnormality robertsonian translocation icon.svg, CC BY 4.0, <https://commons.wikimedia.org/w/index.php?curid=124442249>

<https://mymds.bham.ac.uk/genetics/robtrans.htm>

<https://microbenotes.com/karyotype-karyotyping/>

Task #25

- . **FALSE.** . From inspection of pedigree the mode of inheritance is X-linked recessive.

So, $\sigma^2: q^2 = q \Rightarrow 500 \times 0.2 = 100$ affected σ mice

On the island, there are $500 \times 0.3 = 150$ σ affected.

In the new population: $q' = (100+150)/1000 = 0.25$ (σ genotype frequency)

$q' = 0.25$ (σ)

$p' = 0.75$

$\varnothing$:

$p^2 = 0.75^2$

$2pq = 2(0.75)(0.25)$

$q^2 = 0.25^2$

Affected $\sigma/\varnothing = 0.25/0.25^2 = 4$

so FALSE, not 5

- B. **TRUE.** . Let's first find the probability that the male offspring will have an "performance" phenotype

Female mouse was taken randomly from Scientist A's mice population. frequencies of Scientist A's population:

$p=0.7$

$q=0.3$

$p^2=0.7^2=0.49$

$2pq=2*0.7*0.3=0.42$

$q^2=0.09$

Only $2pq$ and q^2 genotypes can give a rise to "performant" offspring:

if female mice is q^2 , then the portion of "performant" offspring is $q^2=0.09$

if female mice is $2pq$, then the portion of "performant" offspring is $2pq*0.5=0.42*0.5=0.21$

$0.09+0.21=0.3$ ("performant" offspring)

$1-0.3=0.7=70\%$ ("non-performant" offspring)

- C. **FALSE.** . A genotype of mouse 1 is $X^A X^a$ and a genotype of mouse 2 is $X^a Y$

The chance of getting "performant" male offspring from this cross is 0.25, so the chance of getting 4 of them is $0.25^4 \approx 0.0039 = 0.39\%$. This number is more than 0.2%.

- D. **TRUE.** . For mice A and B to have "performant" phenotype, the cross should be: $X^a Y \approx X^A X^a$. From this cross, the chance of getting $X^a Y$ is same to the chance of getting $X^a X^a$

Task #26

- . **TRUE.** . Since different populations of tumor cells will have distinct mutations, a treatment targeting a particular mutation will not be effective in targeting all tumor cells. In addition, some populations of tumor cells might be resistant to therapy while others are susceptible.
- . **FALSE.** . Since mutation in gene A is shared by all regions, it is a better target than mutation in gene D.
- . **TRUE.** . The region R1 does not have a mutation in gene C. Therefore, R1 is likely to expand after targeting with the drug, which targets the mutation in gene C.
- . **FALSE.** . Tumor cells tend to have a higher copy number of oncogenes and a lower copy number of tumor-suppressor genes.

Reference:

Gerlinger M, et al. Intratumor Heterogeneity and Branched Evolution Revealed by Multiregion Sequencing. NEJM. 2012 Mar; 366 (10): 883-892

Task #27

- . **TRUE.** . In a wild-type individual primer sets a+e and b+c did not give PCR products, since primers in a given set bind different chromosomes. In individual 1, both primer sets gave PCR products, indicating a reciprocal DNA exchange between chromosomes, resulting in a translocation.
- . **TRUE.** . Individual 2 has an inversion indicated by a PCR product with primer set c+d. Note that primer d binds DNA at the exon-intron junction, suggesting that inversion changes the primary amino acid sequence. Also, since junctions between exons code the active site, gene H will be non-functional after inversion.
- . **FALSE.** . The size of the PCR product is increased. If it were a deletion, then the size of the PCR product would have decreased.
- . **FALSE.** . Both individuals are heterozygous for the given rearrangement. In addition to PCR products resulting from rearrangements, both individuals have wild-type PCR products.

Reference:

1. Campbell biology, 10th edition, Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson (2014), Pearson
2. Genetics: from genes to genomes, 6th edition, Leland Hartwell, Michael Goldberg, Janice Fischer, Lee Hood, Charles F. Aquadro, Bruce Bejcek (2018), New York, NY: McGraw-Hill Education

Task #28

- . **TRUE.** . From the pedigree, we notice that in individuals having the bb genotype, the A_ genotype results in white hair, while the aa genotype results in black hair. On the other hand, individuals having B_ genotype have black hair regardless of gene A's genotype. From this, we deduce that B is epistatic to gene A.
- . **FALSE.** . Based on the above explanation, AaBb x AaBb cross results in 9 A_B_, 3 A_bb, 3 aaB_, and 1 aabb. From the explanation given to the first question, all individuals having either __B_ or aabb genotype will have black hair, while only A_bb individuals will have white hair. From this, only 3 A_bb will have white hair, the frequency of which is 3/16.
- . **TRUE.** . For individual V-1 to have white hair, he/she has to inherit the b allele from the father. The probability that individual V-1 inherits the b allele from the father (??Bb) is 0.5. Now individual V-1 needs to inherit at least one dominant A allele from either of the parents. Three independent cases can result in this:

V-1 can inherit the dominant allele A from the mother (Aabb), the probability of which is 0.5. In addition, V-1 has to inherit the recessive allele b from the father(??Bb), the probability of which is 0.5 The probability of both events happening together is $0.5 \times 0.5 = 0.25$

If V-1 receives recessive allele a from the mother (probability of which is 0.5), he/she can receive the dominant allele A from the father. Since we don't know the genotypes of individual IV-8's parents, the probability that individual IV-8 will have either AA or Aa genotype is calculated from the Hardy-Weinberg equation, $p^2 + 2pq + q^2 = 1$. If p and q are frequencies of alleles A and a respectively, then the probability of individual IV-8 having a genotype AA is $(p^2) / (p^2 + 2pq + q^2) = (0.4^2) / (0.4^2 + 2 \times 0.4 \times 0.6 + 0.6^2) = 0.16$. In

addition, V-1 still has to inherit recessive allele b, the probability of which is 0.5. The probability of all these events happening together is $0.5 \times 0.16 \times 0.5 = 0.04$

On the other hand, if V-1 receives recessive allele a from the mother (probability of which is 0.5), he/she can receive Dominant allele A from the father with a genotype Aa as well. The probability that the father has genotype Aa is $(2pq) / (p^2 + 2pq + q^2) = (2 \times 0.4 \times 0.6) / (0.42 + 2 \times 0.4 \times 0.6 + 0.62) = 0.48$. Since in this case, the father is heterozygous for the gene A we have to consider the probability that he will pass the dominant allele A to V-1, which is 0.5. Again, V-1 still has to inherit recessive allele b, the probability of which is 0.5. The probability of all these events happening together is $0.5 \times 0.48 \times 0.5 \times 0.5 = 0.06$.

The final probability that the individual V-1 will have white hair is the sum of all these separate cases, $0.25 + 0.04 + 0.06 = 0.35$

D. **FALSE**. . Gene A cannot be located on the X chromosome. If it was located on the X chromosome, the female offspring of individuals III-1 and III-2 must have their father's phenotype.

Reference:

1. Campbell biology, 10th edition, Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson (2014), Pearson
2. Genetics: from genes to genomes, 6th edition, Leland Hartwell, Michael Goldberg, Janice Fischer, Lee Hood, Charles F. Aquadro, Bruce Bejcek (2018), New York, NY: McGraw-Hill Education

Task #29

- . **FALSE**. . There are three Cas9-targetable sites in this DNA, which is determined by the presence of the NGG sequence. There are two NGGs on the top strand of the given DNA and one on the bottom strand.
- . **TRUE**. . Donor sequence-1 (DN-1) has the same gRNA and NGG sequence as in the target DNA. Therefore, Cas-9 can cleave DN-1. On the other hand, a silent mutation in donor sequence-2 (DN-2) disrupts the NGG sequence necessary for Cas9 cleavage. Therefore, Cas9 cannot cleave the donor sequence. The donor sequence must be intact to introduce the desired change into the genome. Hence, DN-2 is a better choice than donor DN-1 for introducing the desired mutation, highlighted in blue.

- . **FALSE.** . Mutation in Mut-2 is a base substitution at the third position of the codon, while mutation in Mut-3 is a base substitution at the first position of the codon. According to Wobble position (third position of the codon, explained in Campbell), the same tRNA anticodon can recognize several codon sequences differing in the third position. Therefore, mutation in Mut-3 is potentially more deleterious than mutation in Mut-2.
- . **TRUE.** . Mutation in Mut-1 results in the deletion of one amino acid, while mutation in Mut-4 results in the frameshift mutation. Therefore, mutation in Mut-4 is potentially more deleterious than mutation in Mut-1.

References:

1. <https://www.stemcell.com/genome-editing-of-human-primary-t-cells-using-the-arcitect-crispr-cas9-system.html>
2. https://en.wikipedia.org/wiki/CRISPR_gene_editing
3. 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 #30

- . **TRUE.** . Based on the results (a lower number indicates that ABd and abD are double crossovers) the order of genes on the chromosome is A-D-B (or B-D-A). The recombination frequency between genes A and B: $(33+31+16+16+1+3) / (200+200+33+31+16+16+1+3) * 100 = 20\%$.
- . **FALSE.** . Remember that only dominant alleles result in functional ENZYME, INHIBITOR, and ACTIVATOR. In the presence of both INHIBITOR and ACTIVATOR, ENZYME is always active (since ACTIVATOR inhibits INHIBITOR). In the absence of INHIBITOR, ENZYME is always active. In the presence of the INHIBITOR and the absence of the ACTIVATOR, ENZYME is always inactive. In the absence of both INHIBITOR and ACTIVATOR, ENZYME is always active.

Now to determine the functions of these genes, first, you need to look at the genotypes, where only one gene has a dominant allele: Abd, aBd, and abD. Then you notice that among these genotypes, only Abd results in orange pigmentation, suggesting that A codes for an ENZYME. Then comparing ABd,

AbD, and ABD, you notice that ABd results in yellow pigmentation, suggesting B is an INHIBITOR, and D is an ACTIVATOR.

C. **FALSE.** . All the offspring will have Aa and EE genotypes. Next, the first parent can only generate two types of gametes: bD and bd, each with an equal probability. The second parent can only generate Bd and bd gametes, each with an equal probability. (The recombination between genes B and D will not result in additional gamete variants.) Based on random fertilization, possible genotypes of the offspring are BbDd, bbDd, Bbdd, and bbdd, each with an equal probability. Among these only Bbdd will result in yellow pigmentation. Therefore, the remaining 75% (not 50%) of the offspring should have orange pigmentation.

TRUE. . Based on the distribution of the offspring among parents with the ee genotype, you notice that all the offspring inheriting the recessive d allele are lethal, suggesting gene D has a redundant role with gene E in larval development. Comparing the genotypes of the parents, you notice that any single offspring will inherit at least one dominant allele of genes D and E. Therefore, all the offspring of the cross between AaBbDDEe and AABbddEe should be viable.

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 #31.

- . **TRUE.** . If there is no LD between dominant alleles of genes A and B, then the frequency of these alleles assorting together in the same gamete is simply the product of the frequencies of individual alleles: $p(AB) = p(A) \cdot p(B)$. (random assortment of alleles of different genes)
- . **TRUE.** . The higher frequency of R2-M* and Q1-M* associations compared to R1-M* and Q2-M* associations indicate that M* arose most likely in the chromosome having alleles R2 and Q1. Since ID-1 was homozygous, then the genotype of ID-1 is most likely R2R2-Q1Q1.
- . **FALSE.** . The small number of R1-M* and Q2-M* chromosomes is most likely due to recombination between M and R/Q. The lower R1-M*

associations than the Q2-M* suggests that M is closer to locus R than to locus Q.

- **TRUE.** . Since ID-1 was homozygous at R and Q, M* can be transferred to the next generation with only one combination of alleles at loci R and Q. In this case, R2 and Q1. Therefore, initially, M* has maximum LD with R2 and Q1. However, M* is now found to be together with the other alleles, R1 and Q2, indicating that the recombination between M and R/Q decreased LD between M* and R2/Q1. Since there is no selection against any allele at loci, R, Q, and M, the same trend should continue in the next thousand years, too.

References:

- Slatkin, M. Linkage disequilibrium — understanding the evolutionary past and mapping the medical future. *Nat Rev Genet* 9, 477–485 (2008). <https://doi.org/10.1038/nrg2361>
- Hästbacka, J., de la Chapelle, A., Kaitila, I. et al. Linkage disequilibrium mapping in isolated founder populations: diastrophic dysplasia in Finland. *Nat Genet* 2, 204–211 (1992). <https://doi.org/10.1038/ng1192-204>

Plant Anatomy and Physiology

Task #32

- . **TRUE.** . It is seen from graph A and B inspection.
- . **FALSE.** . The effect is reversible as seen from fig 1-C, so the statement is false
- . **FALSE.** . as seen from figure 1-C, it both delays and decreases the speed of closure
- . **TRUE.** . it is seen from the graph 1-C

References:

Graph D adopted with changes -----Pavlovič, A., Demko, V., & Hudák, J. (2010). Trap closure and prey retention in Venus flytrap (*Dionaea muscipula*) temporarily reduces photosynthesis and stimulates respiration. *Annals of Botany*, 105(1), 37-44.

All other graphs from ---- Volkov, A. G., Adesina, T., Markin, V. S., & Jovanov, E. (2008). Kinetics and mechanism of *Dionaea muscipula* trap closing. *Plant physiology*, 146(2), 694.

Task #33

- . **TRUE.** . Large cells in the region denoted as B in Figure 1 correspond to vessel elements of the xylem, while cells in the region A correspond to sieve-tube elements of the phloem. Since phloem cells don't divide and are deposited outside the vascular cambium, they cannot cope with increased stem diameter and eventually rupture (Campbell Chapter 35).
- . **TRUE.** . Figure 1 shows that *PtrVCS2* Overexpression mutant decreases vascular cambium layers, suggesting, that *PtrVCS2* limits vascular cambium proliferation. On the other hand, *PtrWOX4a* overexpression increases vascular cambium layers, implying that *PtrWOX4a* is a positive regulator of cambium proliferation. Therefore, *PtrVCS2* and *PtrWOX4a* have opposing roles in regulating vascular cambium proliferation.
- . **FALSE.** . Since *PtrVCS2* negatively regulates cambium proliferation, it might set an upper limit for plant secondary growth. Indeed you can

notice that in Figure 3, the loss-of-function PtrVCS2 mutant has wider stem diameter than the wild-type. However, Figure 2 clearly shows no difference in the primary growth (height) between wild-type and mutant plants. Therefore, PtrVCS2 does not set an upper limit for the primary growth of *P. trichocarpa*.

- . **FALSE.** . Figure 1 shows that the PtrVCS2 Overexpression mutant reduces vascular cambium proliferation. On the other hand, in Figure 3, the loss-of-function PtrVCS2 mutant has relatively less differentiation of vascular cambium to secondary xylem (indicated by less intense Safranin O staining, which stains lignified cell walls of the secondary xylem). These imply that enhanced cambium proliferation DOES NOT NECESSARILY accelerate differentiation of vascular cambium to secondary xylem.

Reference:

1. Dai, X., Zhai, R., Lin, J. et al. Cell-type-specific PtrWOX4a and PtrVCS2 form a regulatory nexus with a histone modification system for stem cambium development in *Populus trichocarpa*. *Nat. Plants* 9, 96–111 (2023).
2. 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 #34

- . **FALSE.** . Since red dye doesn't enter cells, it cannot be a small non-polar molecule that can easily pass the plasma membrane.
- . **FALSE.** . In cross-section A, red dye still penetrates the endodermal layer and enters the vascular system. In contrast, the red dye cannot penetrate the endodermal layer in cross-section B, which suggests that endodermal cells in cross-section B are fully differentiated compared to the ones in cross-section A. Therefore, cross-section A must be closer to the root tip (apical meristem) than cross-section B.
- . **TRUE.** . In Figure 2 cross-section B, the red dye can cross the endodermal layer in the GAPLESS loss-of-function mutant plant, indicating that wild-

type GAPLESS is critical for preventing the transport of substances from the cortex to the vascular system via the apoplast.

- **FALSE.** . The arrangement of the xylem in Figure 2 indicates that the plant species used in this study is a monocot. Monocots typically do not grow in diameter due to the absence of secondary vascular cambium.

References:

1. Song, T., Tian, YQ., Liu, CB. et al. A new family of proteins is required for tethering of Casparian strip membrane domain and nutrient homeostasis in rice. *Nat. Plants* 9, 1749–1759 (2023). <https://doi.org/10.1038/s41477-023-01503-z>
2. 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 #35

- **TRUE.** . In Figure 2, an increase in temperature reduces the absorbance of the PhyB at 725 nm (far-red). Since Phy B exists in two states, Pr and Pfr, and since an equal amount of Phy B was used in each condition, the reduction in the absorbance at 725 nm indicates that less far-red light-absorbing Pfr state is present at the higher temperature than at the lower temperature. Hence, an increase in temperature increases Pfr to Pr conversion. In contrast, red light is responsible for Pr to Pfr conversion. Therefore, red light and an increase in temperature have an opposing effect in determining the phyB state (Pr or Pfr).
- **TRUE.** . In Figure 3, hypocotyl growth is increased in phyB mutants, suggesting that PhyB negatively impacts hypocotyl growth.
- **FALSE.** . In Figure 4, increasing the red-to-far-red light ratio (or increasing the Pfr state) increases the NB size, suggesting that NB size correlates with the amount of Pfr state.
- **FALSE.** . In Figure 4, increasing the red-to-far-red light ratio (or increasing the Pfr state) increases the NB size, suggesting that NB size correlates with the amount of Pfr state. In canopy shade, not enough red light reaches plant leaves due to the absorption of red light by photosynthetic pigments of the shading plant leaves. Therefore, shaded plants mainly

absorb far-red light (explained in Campbell Chapter 39) and the majority of PhyB will be in Pr state. Consequently, NB size will be lower in plants grown under canopy shade. Thus, plant H was more likely to grow under canopy shade conditions than plant K.

References:

1. Legris, M. et al. Phytochrome B integrates light and temperature signals in *Arabidopsis*. *Science* 354 (6314): 897-900 (2016)
<https://www.science.org/doi/10.1126/science.aaf5656>
2. 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 #36

- . **FALSE.** . Compared to short-day conditions, long-day conditions delay flowering and reduce seed size.
- . **TRUE.** . *Lotus japonicus* flowers earlier under long-day (16-hour-day-8-hour-night) than under short-day (12-hour-day-12-hour-night) conditions. Therefore, it must be a long-day (short-night) plant. Disrupting the 12-hour nighttime right in the middle with a flash of red light will be perceived by plants as two short night periods (Campbell Chapter 39). Therefore, disrupting the nighttime right in the middle with a flash of red light should accelerate flowering in *Lotus Japonicus* under 12-hour-day-12-hour-night conditions.
- . **TRUE.** . In CO-transgenic plants, treatment with Dex increases seed size during 2, 4, and 6 days after pollination but not during 8 and 10 days after pollination, suggesting that the activity of CO in increasing seed size is crucial in the earlier stages of embryo development than in the later stages.
- . **FALSE.** . Ovule integuments develop into the seed coat (Campbell Chapter 38). Therefore, a mature ovule determines the seed size before double fertilization. Figure 3 shows that the ovule size is not different between wild-type and co-mutant plants, suggesting that CO is not critical in determining seed size before double-fertilization. On the other hand, in CO-transgenic seeds, increasing the activity of CO by Dex

treatment increases seed size after pollination (hence, after double fertilization). Combined, this suggests that CO-protein regulates seed size only after double fertilization.

References:

Yu, B., He, X., Tang, Y. et al. Photoperiod controls plant seed size in a CONSTANS-dependent manner. *Nat. Plants* 9, 343–354 (2023).
<https://doi.org/10.1038/s41477-023-01350-y>

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 #37

- . **TRUE.** . Auxin travels in plants from the shoot tip downward (polar transport). When applied at end A, the auxin content on the opposite end is relatively higher, compared with the case, when auxin is applied at end B, suggesting end A is closer to the shoot apical meristem than end B.
- . **TRUE.** . Table 1 shows that auxin content in buds is low compared to the auxin content in stems (15 versus 2221), and the content does not change depending on the presence or absence of NPA, an auxin transport inhibitor, suggesting auxin does not have to enter the bud to exert its effect on inhibiting axillary bud growth.
- . **FALSE.** . The grafting experiment shows that the shoot should sense auxin to inhibit branching. Wild-type shoots grafted with an auxin-insensitive root have similar branching with the wild-type shoot grafted to the wild-type root, indicating auxin does not act in the root to inhibit branching. However, mutant shoots grafted with wild-type roots have similar branching to the mutant shoot grafted to the mutant root, further confirming that auxin needs to be sensed in the shoot to inhibit branching.
- . **TRUE.** . Based on Table 2, we notice that ARX1 expression in the xylem alone results in a wild-type branching level, indicating xylem is critical in mediating the inhibitory action of auxin on bud growth.

Reference:

Booker J, Chatfield S, Leyser O. Auxin acts in xylem-associated or medullary cells to mediate apical dominance. *Plant Cell*. 2003 Feb;15(2):495-507. doi: 10.1105/tpc.007542. PMID: 12566587; PMCID: PMC141216.

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 #38

- . **FALSE.** . Figure 1 shows that chemical A inhibits the germination of seeds and isolated embryos, indicating that it increases (not reduces) wheat cultivation time.
- . **TRUE.** . Based on Figure 1, chemical A has more impact on isolated wheat embryos than on whole seeds (compare the length of emerging shoots by approximately calculating the ratio of treated/untreated for each case), suggesting that the seed coat somewhat imposes the barrier for chemical A.
- . **FALSE.** . Adding phytohormone X to the seeds increases the activity of α -amylase (white bands indicate the absence of starch at those positions), suggesting the phytohormone used in the experiment is gibberellin.
- . **FALSE.** . The proteins need to be in their catalytically active folded conformation (not denatured and linearized) to measure the activity of α -amylase.

References:

1. Smailov B, Alybayev S, Smekenov I, Mursalimov A, Saparbaev M, Sarbassov D, Bissenbaev A. Wheat Germination Is Dependent on Plant Target of Rapamycin Signaling. *Front Cell Dev Biol*. 2020 Nov 23;8:606685. doi: 10.3389/fcell.2020.606685. PMID: 33330509; PMCID: PMC7719826.
2. https://en.wikipedia.org/wiki/Lugol%27s_iodine
3. Andrades, A., Contreras, L.M. (2017). Amylase Zymography. In: Wilkesman, J., Kurz, L. (eds) *Zymography. Methods in Molecular Biology*, vol 1626. Humana Press, New York, NY. https://doi.org/10.1007/978-1-4939-7111-4_29

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

Animal Anatomy and Physiology

Task #39

- . **TRUE.** . The patient is very likely to suffer from atherosclerosis, based on the insufficient blood flow to his left leg (decreased pulse pressure is a result of that), which is why lowering the patient's cholesterol levels (particularly VLDL and LDL) and lowering the formation of blood clots by the named types of drugs is among measures to be taken by the patient. However, the existing plaque(s) will remain after this treatment
- . **TRUE.** . Intermittent claudication is a result of ischemia (insufficient oxygen supply) in blocked limb. Lack of oxygen leads to increased synthesis of ATP by anaerobic respiration, which leads to accumulation of metabolic acids and hence to decrease in pH. pH is monitored by chemoreceptors, threshold of which is not affected by prostaglandins. That is the reason aspirin will have no effect as a painkiller.
- . **FALSE.** . Systemic hypertension increases the blood pressure on a wide scale - it does not affect a single limb, as in this case. Besides, the pulse pressure is obviously decreased in the left leg of this patient - a sign of an obstruction (atherosclerotic plaque) and not of a hypertension
- . **TRUE.** . Heart failure forces the heart to pump at force exceeding its capability for an extended time. Beta-blockers can make the condition better by reducing heart load - by acting as vasodilators they reduce pressure in the systemic circulation and thus reduce the pressure that has to be built up in order to pump blood into the aorta. This will reduce heart load.

Reference:

https://academic.oup.com/bja/article/117/suppl_2/ii95/1744168
[https://www.ncbi.nlm.nih-](https://www.ncbi.nlm.nih.gov/easyaccess2.lib.cuhk.edu.hk/pmc/articles/PMC6497514/)
[gov.easyaccess2.lib.cuhk.edu.hk/pmc/articles/PMC6497514/](https://www.ncbi.nlm.nih.gov/easyaccess2.lib.cuhk.edu.hk/pmc/articles/PMC6497514/)
<https://www.ncbi.nlm.nih.gov/books/NBK235/>

Task #40

- . **TRUE.** . After absorption, oral prodrugs have to undergo through first-pass metabolism, after which they become active and exert therapeutic effect. Drugs with high first-pass metabolism become reach the concentration of their active form sufficient for therapeutic effect faster than those with low first-pass metabolism, which is why oral administration is more suitable for them (in general).
- . **TRUE.** . Such drugs are restricted to plasma, that is to 3 liters of body fluid. Drugs that get distributed into cells and tissue fluids have much higher values of V.
- . **TRUE.** . No binding to plasma proteins means high rate of dissipation across tissues because of hydrophobic nature of the drug. The higher the blood flow to the organ the higher will be the rate of amount of drug reaching it. The liver is one of the organs most supplied with blood, which is why the rate of elimination will be great, and the half-life will be short.
- . **TRUE.** . Estrogen (active component of the named pills) structurally resembles cholesterol and its metabolites, including bile salts. Therefore, after estrogen from the pills reaches liver, it either reaches systemic circulation (small portion) or gets excreted via bile (rest of the dose), with the latter portion getting reabsorbed afterwards. This circle significantly increases half-life of estrogen, which accounts for the longevity of its action.

Reference:

Talevi, Alan & Quiroga, Pablo. (2018). ADME Processes in Pharmaceutical Sciences Dosage, Design, and Pharmacotherapy Success: Dosage, Design, and Pharmacotherapy Success

Tripathi, K. D. Essentials of medical pharmacology. 8th ed. Jaypee Brothers Medical. 2018

Task #41

- . **TRUE.** . As it is seen from the figure 1a, and 1b, after 3 days of feeding there is an increase in heart mass and at the same time DNA mass (ng/mg of ventricular tissue) is decreasing, which means no new cell division is occurred and increase in size (hypertrophy) took place.
- . **TRUE.** . It is directly seen from the figure 1C
- . **FALSE.** . Animal S corresponds to Burmese Python, there should be a 40 % increase after feeding as it is given in figure 1a.
- . **TRUE.** . It is evident from the figure 1a that BSA+ W shows increase in heart size almost as when adding fed plasma to fasting snakes. The increase level is lower since, fed plasma might contain other factors as well.

Reference:

Reference adopted from Animal physiology by Hills, Wyse, Anderson 4th edition.

Figures were adopted with modifications.

Task #42

- . **TRUE.** . From the equation, this condition makes π_c value low, so overall pressure difference becomes more negative, which in turn causes J_v value to be more positive, leading to increased filtration rates
- . **TRUE.** . Any changes to wall intactness will affect the K_f value. BRS physiology by Linda Costanzo, 4th ed. Page 95.
- . **TRUE.** . As seen from formula, any changes in venous pressure 5 times more stronger than changes in arterial pressure. since constriction increases the pressure, overall statement is true.
- . **TRUE.** . Since some liver cells involved in protein synthesis, they should be able to excrete produced proteins into the blood, thus they should have capillaries very permeable to large molecules to pass, therefore oncotic pressure gradient becomes less significant, which in turn makes hydrostatic pressure gradient very important factor for the fluid exchange

Reference:

BRS physiology by Linda Costanzo, 4th ed. Page 95.

Cardiovascular Physiology Concepts (2011) 2nd ed. chapter 8, 189 page

Task #43

- . **FALSE.** . it is evident from figure 1a
- . **TRUE.** . Everything absorbed in the intestine (including toxins) will come via portal vein, and thus the first zone to face toxins is zone 1 and its concentration gradually decreases toward the central vein.
- . **FALSE.** . Being unable to secrete bile salts means that there is 0 at X axis, and from the graph bile flow is lower in Rabbits at this point.
- . **TRUE.** . 1500 grams of liver produces $1500 \times 17 = 25500 \mu\text{L}$ per 60 min. Then from simple proportion, $(25500 \times 40) / 60 = 17000 \mu\text{L}$ of bile for 40 min, or 17 ml.

Reference:

for images 1a ---- [The liver \(cell.com\)](http://cell.com)

animals Bile flow graph was adopted from Boyer JL. Bile formation and secretion. Compr Physiol. 2013 Jul;3(3):1035-78. doi: 10.1002/cphy.c120027. PMID: 23897680; PMCID: PMC4091928.

Task #44

- . **TRUE.** . As it is seen from graph B, smaller insects have almost no-temperature difference in head, thorax and abdomen regions, therefore this mutation would have a minimal impact on them.
- . **TRUE.** . As mutation implies that abdomen cannot be warmed effectively, this will bring abdomen temperature to become identical to the outside temperature
- . **FALSE.** . As it is seen from graph 1-D, at higher thorax temperature metabolic rate decreases, meaning mut99 bee cannot efficiently cool the thorax, therefore cannot attain high metabolic rate compared to normal bee

- . **FALSE.** . As it is seen from graph 1-C, wing beat frequency is independent of body mass.

Reference:

Reference: Size-dependent Scaling of Stingless Bee Flight Metabolism Reveals an Energetic Benefit to Small Body Size - PubMed (nih.gov)

Reference for figure 1-I modified from Animal physiology by Hills, Wyse, Anderson 4th edition, chapter 10, page 282

Task #45

- . **TRUE.** . Person 1 is a COPD patient with increased EELV value. This patient after expiration always have positive pressure left in alveoli, thus his respiratory muscles need to counteract this pressure and thus always under tonus and thus even at relaxed state it will be a bit shorter (will have shorter sarcomere length) and therefore his muscles cannot generate higher force during contraction compared to person 2 who does not have this positive pressure left after expiration
- . **FALSE.** . In COPD patients TLC will increase mainly because of increase of RV and air trapping in the lung, so absolute value will increase. See fig 1-B
- . **FALSE.** . Correct answer is found by 1) understanding what each lines and arrows indicate, then to match with the data given in the figure 1B. solid line —: end-inspiratory lung volume; line -----: end-expiratory lung volume; arrow: tidal volume; dotted arrow: inspiratory reserve volume; open arrow: inspiratory capacity. The correct matching is Figure T – severe, Figure Z – moderate, Figure E – mild degrees of COPD
- . **FALSE.** . RV is not included in the graph 1C, Y line represents VC which does not account for RV

References:

For figures 9 - 1 -----doi:10.1186/2049-6958-9-19 Cite this article as: Sanguinetti: The lungs need to be deflated: effects of glycopyrronium on lung hyperinflation in COPD patients. Multidisciplinary Respiratory Medicine 2014 9:19

For figure 9-2 Calverley, P. M. A., & Koulouris, N. G. (2005). Flow limitation and dynamic hyperinflation: key concepts in modern respiratory physiology. European Respiratory Journal, 25(1), 186-199.

Task #46

- . **FALSE.** . As seen from graph B,C,D there is no difference in activity compared to control
- . **TRUE.** . ATP is more important after hypo osmotic stress
- . **FALSE.** . Such experiment was not performed and thus, there is no data so not evident, thus False
- . **TRUE.** . This is evident from the graph D

References:

All graphs adopted from : Hvidepil LKB and Møbjerg N (2023), New insights into osmobiosis and chemobiosis in tardigrades. Front. Physiol. 14:1274522. doi: 10.3389/fphys.2023.1274522

Task #47

- . **FALSE.** . The T cell shown in Figure 1 is a CD8-positive cytotoxic T-cell, which is not involved in antibody production.
- . **TRUE.** . The antibody against PDL-1 potentially prevents its interaction with PD-1, thereby preventing its inhibitory action on the T cell.
- . **FALSE.** . In the question text it is stated that tumor cells hijack physiological pathways regulating T-cell activity, indicating checkpoint inhibitors might over-activate the immune system. Indeed, one possible side-effect of using checkpoint inhibitors is the development of auto-immune disorders. Compared to Patient R, Patient Z's serum contains antibodies binding to the human epithelial cells, suggesting Patient Z might have an auto-immune disorder. Therefore, immunotherapy might not be the ideal solution for Patient Z.
- . **FALSE.** . The question text states that the more neoantigens present on the surface of tumor cells, the higher the efficiency of immunotherapy. Therefore, defects in DNA mismatch-repair → accumulation of mutations

→ production of mutated proteins → more neoantigens → more tumor cells are destroyed by immune cells. Therefore, defects in mismatch repair increase the efficiency of immunotherapy. Consequently, since the only significant difference between cohort A and B tumors is the presence or absence of DNA mismatch repair, cohort A rather than cohort B is more likely to have DNA mismatch repair deficient tumors.

Reference:

1. Campbell biology, 10th edition, Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson (2014), Pearson
 2. Sharpe, A., Pauken, K. The diverse functions of the PD1 inhibitory pathway. *Nat Rev Immunol* 18, 153–167 (2018). <https://doi.org/10.1038/nri.2017.108>
 3. Martins, F., Sofiya, L., Sykiotis, G.P. et al. Adverse effects of immune-checkpoint inhibitors: epidemiology, management and surveillance. *Nat Rev Clin Oncol* 16, 563–580 (2019). <https://doi.org/10.1038/s41571-019-0218-0>
 4. Ramos-Casals, M., Brahmer, J.R., Callahan, M.K. et al. Immune-related adverse events of checkpoint inhibitors. *Nat Rev Dis Primers* 6, 38 (2020). <https://doi.org/10.1038/s41572-020-0160-6>
 5. Nasarallah, G. K., et al. (2022). "Detection of Antinuclear Antibodies Targeting Intracellular Signal Transduction, Metabolism, Apoptotic Processes and Cell Death in Critical COVID-19 Patients." *Mediterr J Hematol Infect Dis* 14(1): e2022076 → Figure 2
- Le, D. T., et al. (2015). "PD-1 Blockade in Tumors with Mismatch-Repair Deficiency." *N Engl J Med* 372(26): 2509-2520 → Figure 3

Task #48

- . **TRUE.** . From Figure 1 we can see that unmodified RNA has the highest potential to activate dendritic cells, thereby immune reaction. Therefore, human cells are expected to modify their RNAs to avoid auto-immune response.
- . **FALSE.** . In Figure 1, s2U has the highest potential to avoid immune response. However, Figure 2 shows that RNAs having s2U modifications

are not efficiently translated into proteins. Therefore, it is unlikely that mRNAs having s2U modification will be efficient in generating viral antigens.

- . **FALSE.** . Figure 1 shows that pseudouridine has a lower potential to activate immune response to RNA. In addition, mRNAs containing pseudouridine have higher translation efficiency. Therefore, mRNA vaccines are more likely to have pseudouridine than m5C.
- . **FALSE.** . Indeed, leukocytes can serve as a host. However, erythrocytes do not possess ribosomes. Therefore, erythrocytes cannot serve as a host to translate mRNA into viral antigens.

Reference:

1. Karikó, K., Buckstein, M., Ni, H. and Weissman, D. Suppression of RNA Recognition by Toll-like Receptors: The impact of nucleoside modification and the evolutionary origin of RNA. *Immunity* 23, 165–175 (2005) → Figure 1
2. Karikó, K., Muramatsu, H., Welsh, F.A., Ludwig, J., Kato, H., Akira, S. and Weissman, D. Incorporation of pseudouridine into mRNA yields superior nonimmunogenic vector with increased translational capacity and biological stability. *Mol Ther* 16, 1833–1840 (2008). → Figure 2

Task #49

- . **FALSE.** . In Figure 2, we observe that only protein supplement enhances the expression of CCHa1. Protein supplements' caloric content is in between sugar and fat; therefore, the caloric content of the diet cannot explain the results of Figure 2.
- . **TRUE.** . Figure 2 shows that supplementing regular food with the protein enhances the expression of CCHa1, while Figure 3 shows that CHHa1 is critical for preventing arousal during sleep. Therefore, results suggest that a protein-rich diet reduces sleep arousal.
- . **TRUE.** . Disruption in exocytosis means neurons are unable to release neurotransmitters at the synapse. Figure 4 shows that the shi-ts mutant increases arousal during sleep compared to the control, suggesting that exocytosis (release of neurotransmitters) is necessary for preventing arousal. An action potential should propagate along the axon for the neuron to release neurotransmitters (Campbell Biology, Chapter 48).

Therefore, CCHa1 should result in an action potential in DA neurons to prevent arousal during sleep.

- . **FALSE.** . Based on the given information, two scenarios are possible. As a Na⁺ channel, TrpA can depolarize the membrane, resulting in action potential. As a Ca²⁺ channel, it can increase neurotransmitter release (Campbell Biology, Chapter 48). In both cases, TrpA1 activates the neuron. Figure 4 shows that overexpression of TrpA1 prevents arousal during sleep, suggesting the MBON neuron needs to be active to prevent arousal. Therefore, the synapse between DA and MBON neurons must be excitatory rather than inhibitory.

References:

Titos, I. et al., A gut-secreted peptide suppresses arousability from sleep. *Cell* 186, 1382–1397 (2023)

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 #50

- . **FALSE.** . The concentration gradient of bicoid mRNA inside the unfertilized oocyte is critical for determining the anterior-posterior axis of the embryo. Depletion of bicoid inside male testes should not affect the development of the *Drosophila* embryo.
- . **FALSE.** . Figure 2 shows that high amounts of bicoid protein are necessary for acron development. Since Exuperantia anchors bicoid mRNA at the anterior end of the oocyte, the concentration gradient of bicoid will not be maintained properly in Exuperantia mutants. Therefore, less than the necessary amount of bicoid protein will present at the anterior end of the embryo, which subsequently leads to the absence of acron in the Exuperantia mutants. Indeed, Exuperantia mutants have no acron and heads; instead, they have extended thorax regions.
- . **TRUE.** . Torpedo-deficient oocytes develop normally, suggesting that Torpedo is not required in oocytes for establishing the normal dorsal-ventral axis.
- . **TRUE.** . Torpedo-deficient follicles result in an entirely ventral embryo, suggesting torpedo is important for maintaining the future dorsal side of

the embryo. Since the given information states that the interaction between the gurken and torpedo is critical for determining the dorsoventral axis of the embryo, the region concentrated with the gurken must result in the dorsal structures in the developing embryo.

References:

Developmental Biology, 11th Edition, Scott F. Gilbert and Michael J. F. Barresi, Sinauer Associates, Inc.