

Singapore Biology League 2024

Adrenaline Rush Problems

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All figures are credited in the answer document.

AR Grids

Easy

Animals	Plants	Cell Biology	Genetics	Ecology
<u>EA 1: Moo Moo</u>	<u>EP 1: A tall order</u>	<u>EC 1: Membranous Membranes</u>	<u>EG 1: Pedigree Mystery</u>	<u>EE 1: A Helping Hand</u>
<u>EA 2: This feels a little fishy</u>	<u>EP 2: A green liquid</u>	<u>EC 2: It's just a phage</u>	<u>EG 2: Endosymbiosis again?? And again??</u>	<u>EE 2: Wormie</u>
<u>EA 3: Mortis – Creature of the Night</u>	<u>EP 3: Don't be salty</u>	<u>EC 3: Let's get this bread</u>	<u>EG 3: Basic Maths</u>	<u>EE 3: Set in their ways</u>
<u>EA 4: I am hungry</u>	<u>EP 4: GSI CSI</u>	<u>EC 4: Don't lose concentration!</u>	<u>EG 4: Bzzzzzz</u>	<u>EE 4: Shortest question ever</u>

Medium

Animals	Plants	Cell Biology	Genetics	Ecology
<u>MA 1: Insulin Man</u>	<u>MP 1: It's hot in here</u>	<u>MC 1: 2,4-difluorotoluene</u>	<u>MG 1: Beta</u>	<u>ME 1: Chalky Business</u>
<u>MA 2: Squidward</u>	<u>MP 2: A Tall Plant</u>	<u>MC 2: Cultured in Biology</u>	<u>MG 2: You get one, everyone gets one</u>	<u>ME 2: Hey mate!</u>
<u>MA 3: Don't be self-absorbed!</u>	<u>MP 3: Callous question; Don't be careless!</u>	<u>MC 3: Roly-Poly</u>	<u>MG 3: The val operon</u>	<u>ME 3: Overcrowded school canteen</u>
<u>MA 4: Heart's a Ball</u>	<u>MP 4: Plants breathe too!</u>	<u>MC 4: Cell division = Multiplication</u>	<u>MG 4: I hate ants</u>	<u>ME 4: The Emoji Question</u>

Hard

Animals	Plants	Cell Biology	Genetics	Ecology
<u>HA 1: Live Laugh Love</u>	<u>HP 1: Cyber Green</u>	<u>HC 1: Gibby Gibby Gibby</u>	<u>HG 1: Haus Habsburg</u>	<u>HE 1: Lead the way</u>
<u>HA 2: Breathe in and out</u>	<u>HP 2: Electrochemistry of life</u>	<u>HC 2: Steady lah!</u>	<u>HG 2: Caryotyping</u>	<u>HE 2: Impostor</u>
<u>HA 3: I want to pee</u>	<u>HP 3: I'll try to fix you</u>	<u>HC 3: Alpha and Beta</u>	<u>HG 3: Reversi</u>	<u>HE 3: The Sun's a Deadly Lazer</u>
<u>HA 4: T-Rex Rexsurrection</u>	<u>HP 4: Swiss Food & Beverage Establishment</u>	<u>HC 4: Bubbles</u>	<u>HG 4: Same same but different</u>	<u>HE 4: La Signora's Lackeys</u>

EA 1: Moo Moo

Smallpox is a disease caused by the variola virus, a member of the Orthopoxvirus family. It is very contagious and has caused millions of fatalities. While it was eradicated in 1980, it has caused over 300 million deaths in just the 20th century alone.

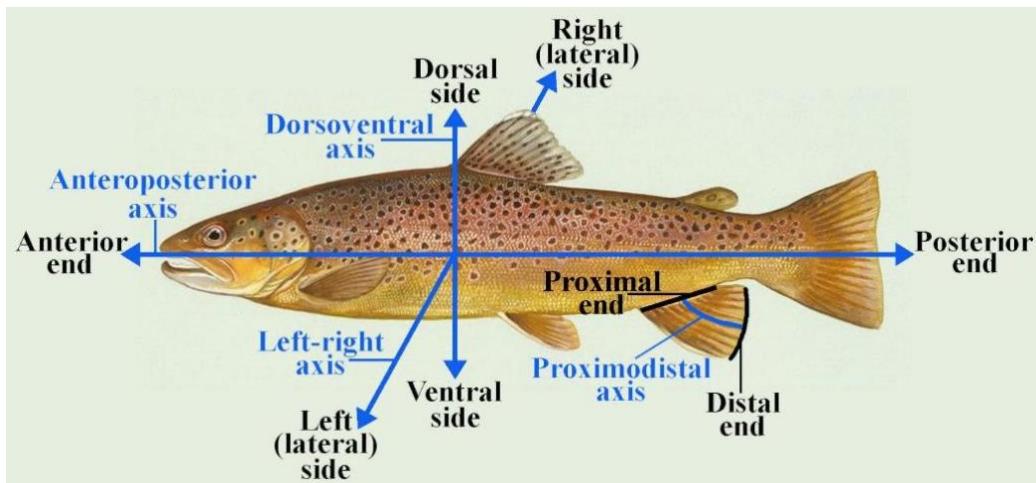
In 1796, English Doctor Edward Jenner conducted an experiment on two persons. First, the material from a cowpox sore on milkmaid Sarah Nelmes was inoculated into the arm of 8-year-old James Phipps who was his gardener's son. After several months, James Phipps was exposed to the smallpox virus, but he never developed smallpox.

Which of the following is the most valid conclusion from the experimental results?

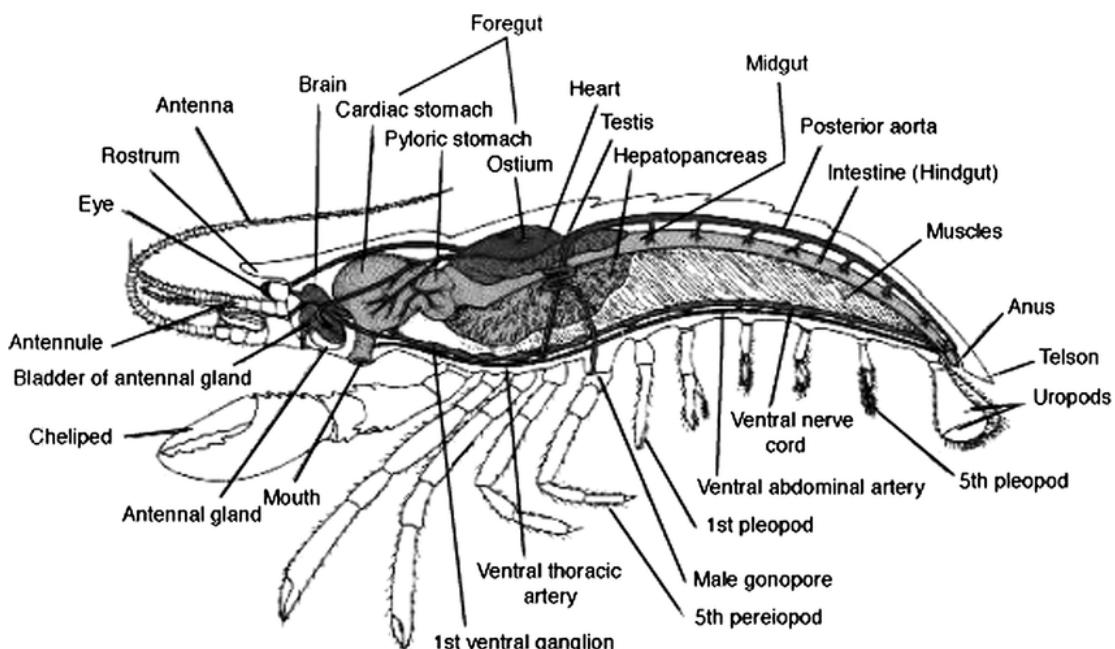
- A. Cowpox cannot be transmitted to humans (no zoonosis).
- B. The material from the cowpox sore contains the virions of cowpox.
- C. Cowpox is transmitted via transfer of bodily fluids and not by air.
- D. James Phipps became immune to smallpox due to exposure to cowpox material.

EA 2: This feels a little fishy

The diagram below shows the anatomical terms of location in a fish.



Many fish in the ocean hunt and eat shrimp. The internal anatomy of a shrimp is seen below.

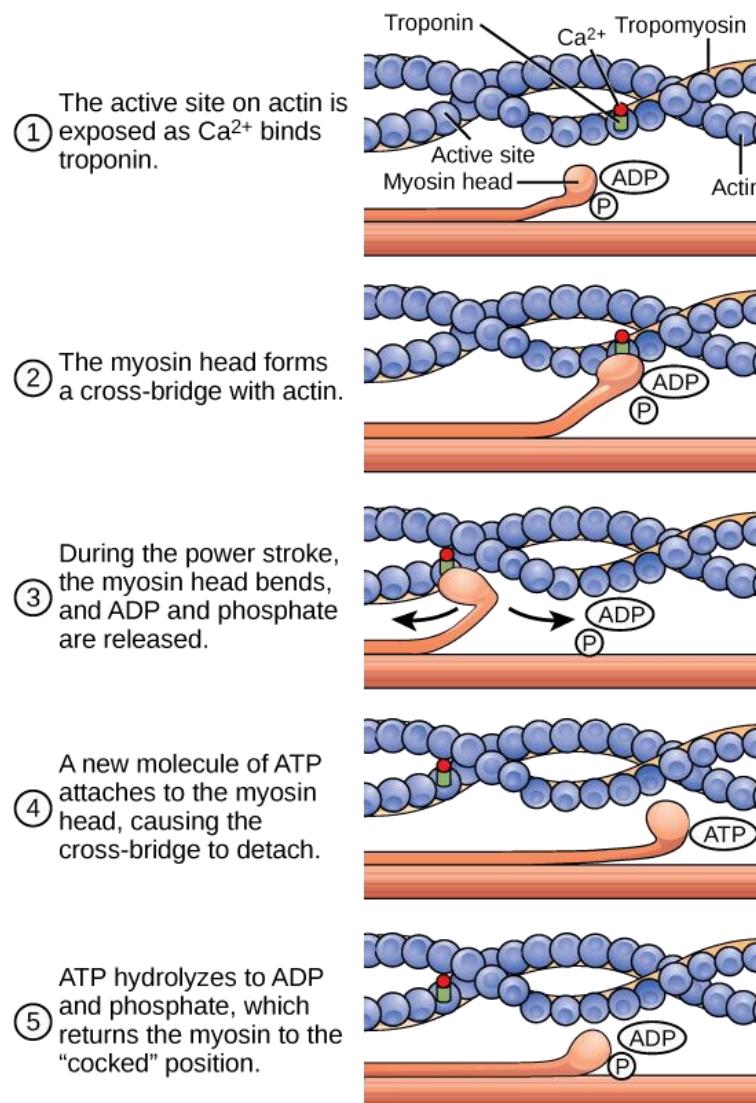


Which of the following anatomical descriptions of the shrimp is correct?

- The foregut is posterior to the testis.
- The cheliped is ventral to the pereiopods.
- The uropods are paired and lie posterior to the mouth.
- The telson is distal to the uropods.

EA 3: Mortis – Creature of the Night

Muscles are made of actin and myosin filaments. When calcium ions bind to troponin, it exposes the active sites on actin, allowing the myosin head to bind to the actin filament. The myosin head then bends allowing the muscle to contract, releasing ADP and P_i . To allow the cycle to repeat, a new ATP molecule must bind to the myosin head as the hydrolysis of ATP will allow the myosin head to continue to bind to the actin filament.



Rigor mortis is a phenomenon that occurs in the muscles after death where ATP is rapidly depleted in the body. By considering the muscle contraction cycle and the effect after ATP is depleted, which of the following outcomes after death is **incongruent** with rigor mortis?

- A. Locked jaw
- B. Urination and defecation
- C. Arm held upwards towards the sky
- D. Difficulty in folding the limbs

EA 4: I am hungry

A balanced diet is important for the growth of children as well as the maintenance of overall health. It is important to take note of the levels of fats, proteins and vitamins in one's diet.

The table below shows the composition of the current diets of four children.

Individual	Saturated Fats	Protein	Vitamin				
			A	B1 (Thiamine)	B9 (Folate)	C	D
Amy	High	Normal	Low	Low	Normal	High	Normal
Bernadette	High	Low	Normal	Normal	Low	Low	Low
Cooper	Low	High	Low	Normal	High	Low	Normal
Denise	Low	Low	Low	Normal	Low	Normal	Low

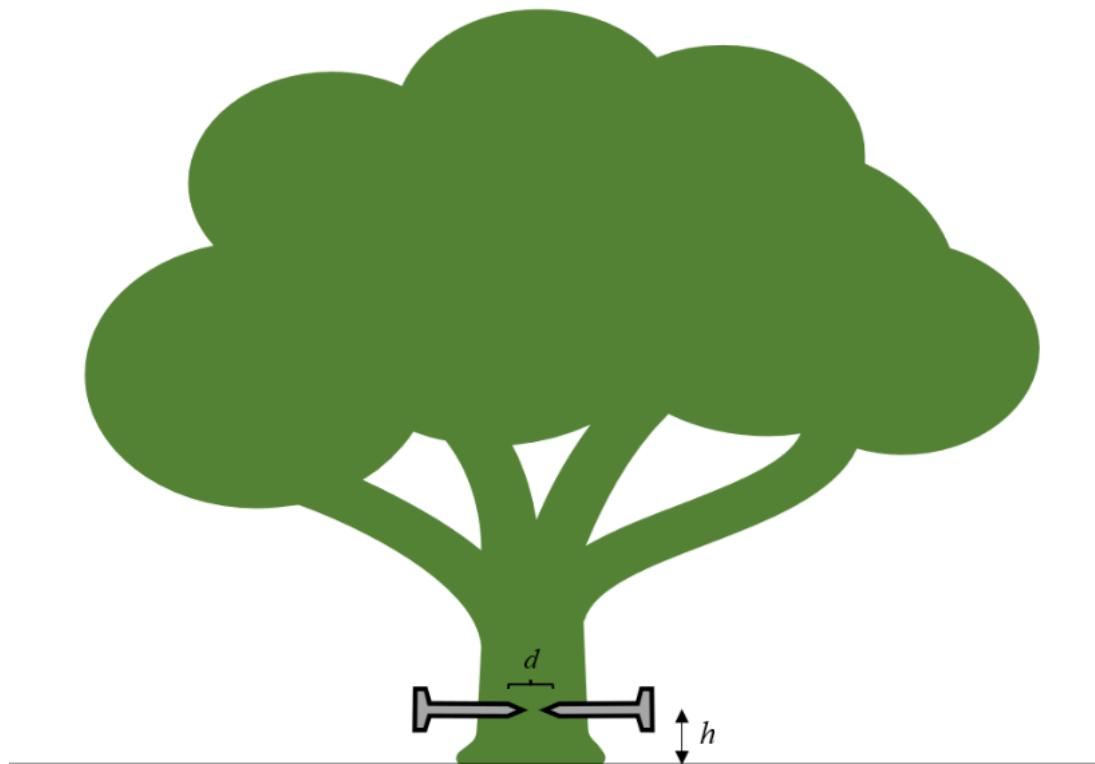
Which diseases are likely present in each individual?

- A. Amy: Kwashiorkor and xerophthalmia
- B. Bernadette: Neural tube defects and scurvy
- C. Cooper: Anaemia and beriberi
- D. Denise: Kwashiorkor and rickets

EP 1: A tall order

One of the most iconic trees in Singapore is the rain tree, *Samanea saman*. Rain trees can grow to very high heights and have a very thick trunk. Rain trees are able to achieve this by both primary and secondary growth. Primary growth occurs from the apical meristem at the top of the tree, while secondary growth occurs in the cambium with new tissues added outwards.

To commemorate SG50, Matilda nails two nails horizontally on opposite sides of the trunk of a rain tree as seen in the figure below in 2015.



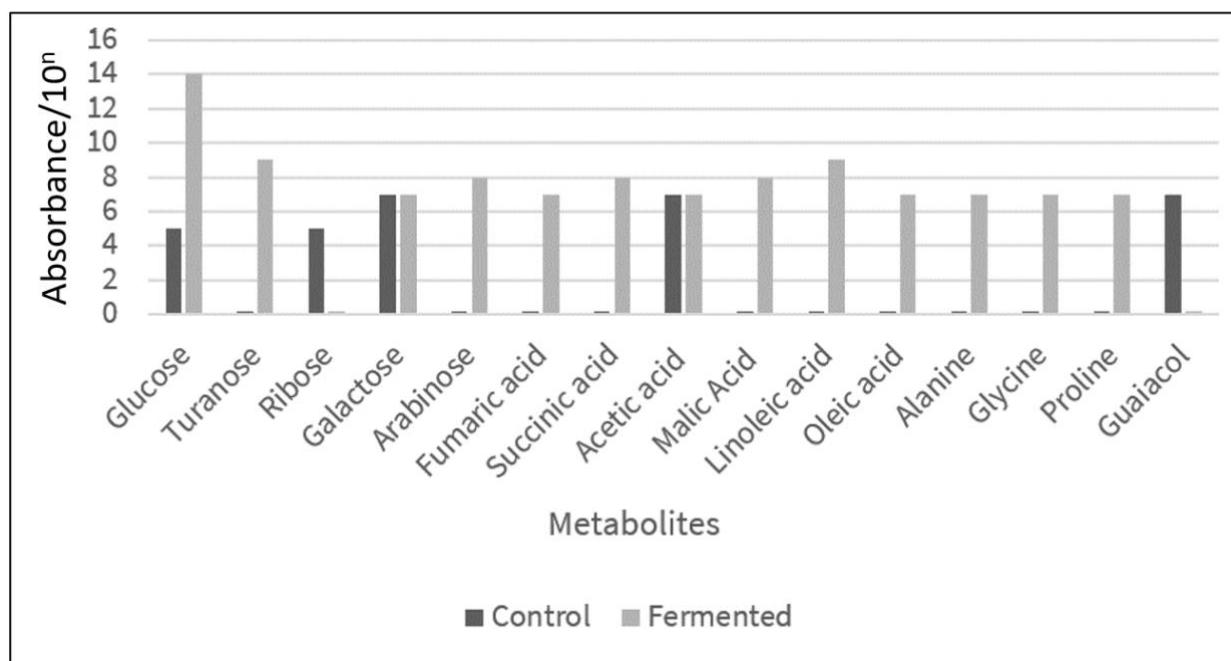
Excited for 2025, Matilda wishes to predict the changes in the tree before seeing it. What can Matilda expect to be the change in the distance d between the two nails and the change in the height h of the nails above the ground?

- A. Increase, unchanged
- B. Increase, increase
- C. Unchanged, decrease
- D. Unchanged, increase

EP 2: A green liquid

Saccharum officinarum is more commonly known as sugarcane in Singapore. After fermentation of sugarcane juice, you decided to make use of solid-state fermentation to extract nutrients out of the leftover residue, known as bagasse. You fermented 10g of bagasse with 10^5 CFU of Fungus A and incubated it for 48h at 30°C. You also incubated another 10g of bagasse without fermentation together with it as a control. Metabolite levels were then detected using gas chromatography-mass spectrometry (GC-MS).

The results are seen in the figure below.



Several statements regarding the data were made.

- I. The amount of glucose increased by about 2.25 times after fermentation.
- II. Fungus A likely produces proteases.
- III. Fungus A likely produces lipases.
- IV. Fungus A likely only undergoes anaerobic and not aerobic respiration.
- V. The bagasse after fermentation will likely have a higher pH.

Which of the above statements are true?

- A. I, II, III only
- B. I, II, IV only
- C. II and III only
- D. II and V only

EP 3: Don't be salty

Singapore is home to over 30 species of mangrove plants, with many being found in the Sungei Buloh Wetland Reserve. The figure below shows the Eye of the Crocodile (*Bruguiera hainesii*). It is a mangrove plant that is critically endangered in Singapore with approximately 200 individuals in the world.



Mangrove plants are found in the intertidal zone, and thus they have to deal with waterlogged, anoxic soil and high salinity. One way that mangrove plants have adapted to such conditions is to have prop roots, allowing salt water to pass through while preventing its absorption.

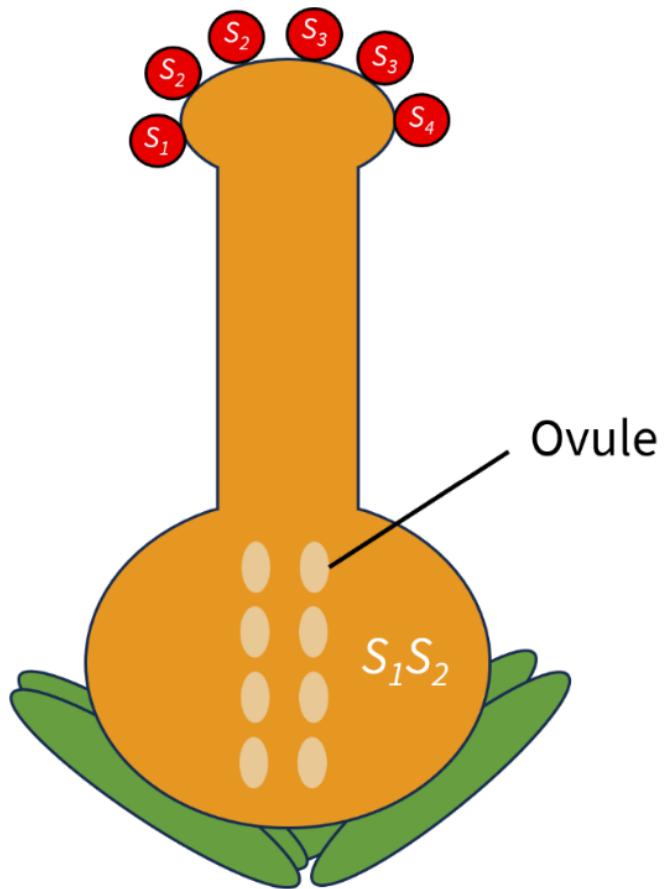
Which of the following is **not** an adaptation that mangrove plants have developed to deal with these two problems?

- A. Salt-secreting glands on leaves
- B. Capture of non-salty rainwater by ends of root that emerge out of the soil
- C. Seeds germinate while attached to parent plant
- D. Lenticels in prop roots for aeration

EP 4: GSI CSI

Gametophytic self-incompatibility (GSI) is a mechanism that some plants use to prevent self-pollination and promote cross-pollination. Whether fertilisation occurs is determined by the self-incompatibility alleles (S-alleles). A pollen grain with a certain S-allele cannot fertilise the ovules of a plant which has the same S-allele in its genotype.

In a population of buttercup plants that make use of GSI, there are ten different S-alleles (S_1, S_2, S_3, \dots). Six pollen grains with S-allele as indicated in the figure were transferred to the stigma of a different buttercup plant with a genotype of S_1S_2 .



How many different genotypes of the zygote can be formed in this cross?

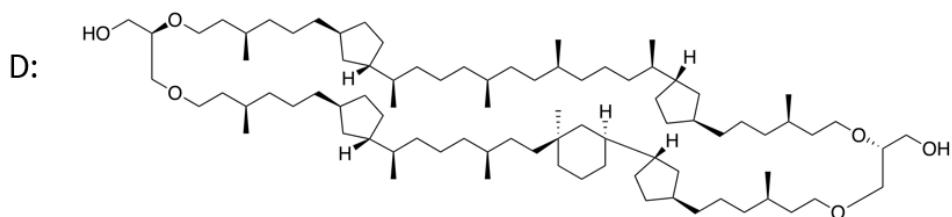
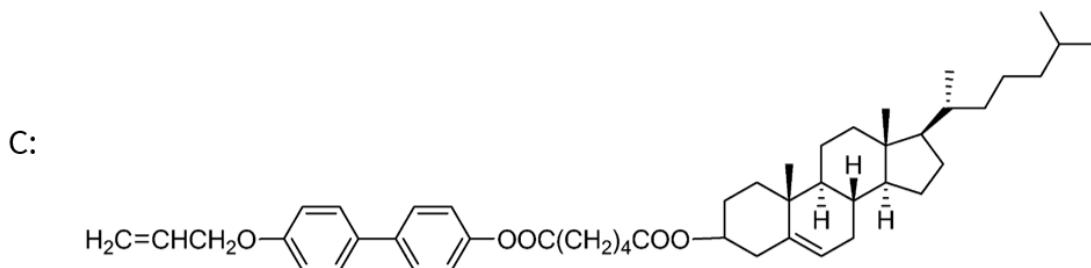
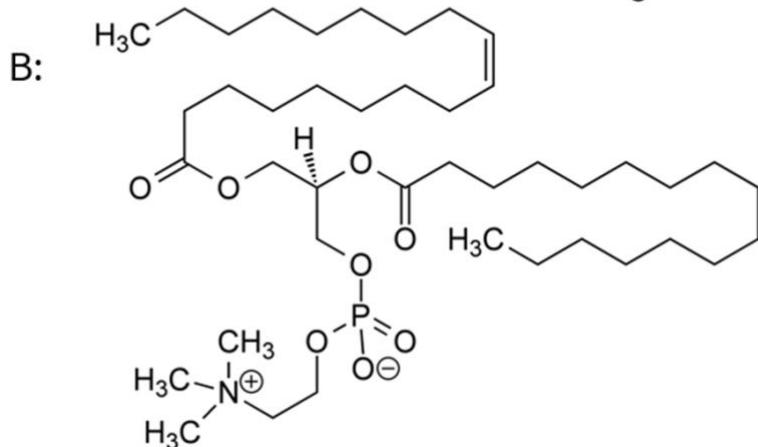
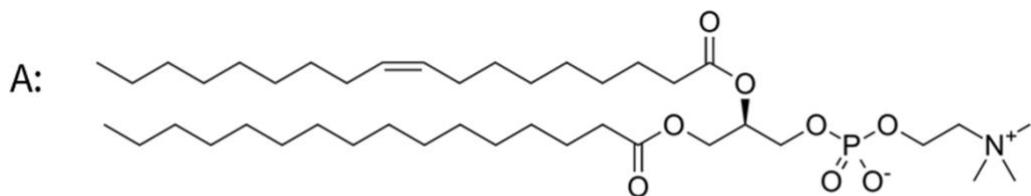
- A. 2
- B. 3
- C. 4
- D. 5

EC 1: Membranous Membranes

Plasma membranes are present in all cells as they serve to divide the intracellular environment with the extracellular environment. Plasma membranes are usually made of two layers of phospholipids, forming a phospholipid bilayer.

Imagine you created a new species of organisms with cells that contain plasma membranes too. However, the plasma membrane is only made of a single layer of phospholipids.

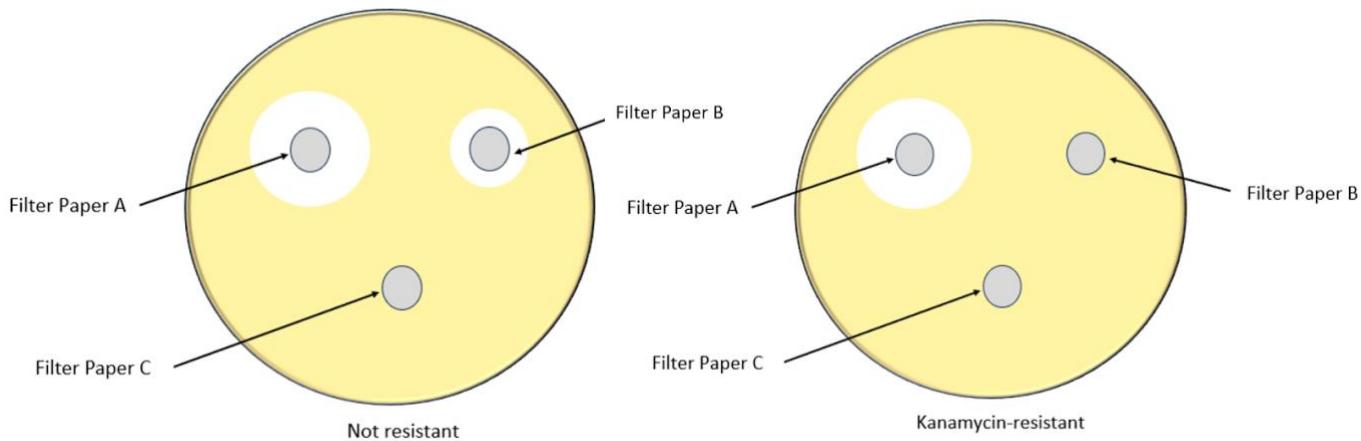
By considering the structure of the plasma membrane, which of the following could most likely form the single-layer plasma membrane?



EC 2: It's just a phage

To investigate the effects of bacteriophages and antibiotics on *E. coli*, two strains of *E. coli*, one not resistant and another resistant to kanamycin were used.

Filter paper soaked with CTX φ phages (temperate phage), T₂ phages (lytic phage), and kanamycin were placed on an agar plate with either the resistant or non-resistant strain of *E. coli*. After incubation overnight at 37°C, the following results were seen.



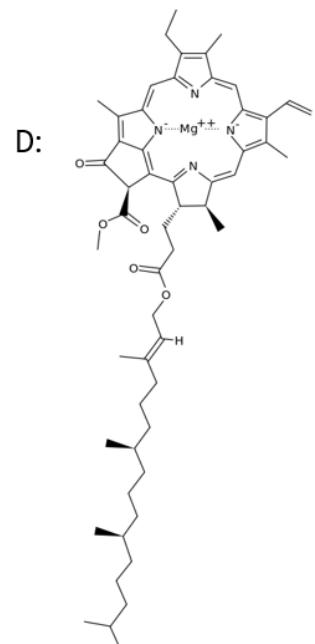
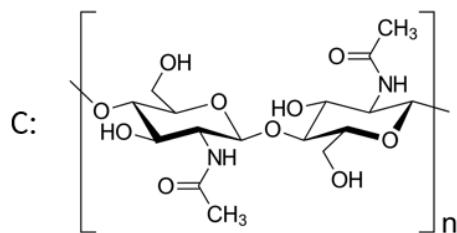
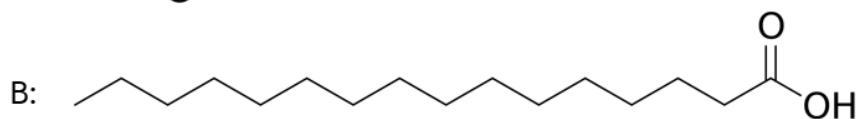
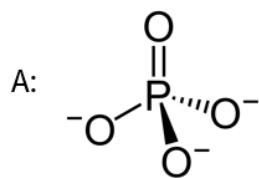
Match the filter paper to in what it was soaked.

	Filter Paper A	Filter Paper B	Filter Paper C
A.	T ₂ phage	Kanamycin	CTX φ phage
B.	T ₂ phage	CTX φ phage	Kanamycin
C.	CTX φ phage	Kanamycin	T ₂ phage
D.	CTX φ phage	T ₂ phage	Kanamycin

EC 3: Let's get this bread

Wonton noodles is a dish of Cantonese origin that is often cooked with pork lard. Avery was eating wonton noodles with soup and noticed that the pork lard in the soup still remained crispy. However, when she added toasted bread pieces (croutons) to the soup, the croutons became soft and no longer crispy.

Which of the following molecules explain this phenomenon?



EC 4: Don't lose concentration!

Hypertonicity refers to the solution having a lower solute potential than the cell sap, while hypotonicity refers to the solution having a higher solute potential than the cell sap.

Several statements regarding the effects of solutions with different tonicities are listed below.

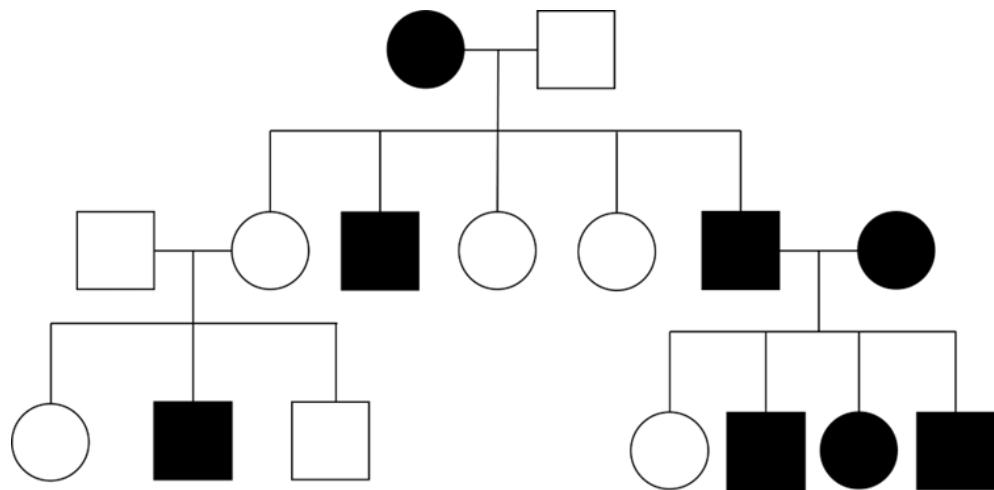
- I. An enucleated red blood cell placed in a hypertonic sucrose solution will crenate.
- II. An animal cell placed in a hypotonic sucrose solution will lyse.
- III. When a plant cell is placed in a hypertonic sucrose solution, the sucrose solution will enter the cell sap.
- IV. A plant cell placed in distilled water will become turgid.
- V. A bacterial cell placed in distilled water will lyse.
- VI. A naked virion, of the family Parvovirus, placed in distilled water will lyse.

Which of the above statements are true?

- A. I, II, IV only
- B. I, II, IV, V, VI only
- C. II, III, IV, V only
- D. II, IV, VI only

EG 1: Pedigree Mystery

Dr Pahari cannot figure out the pattern of inheritance of the disease below. Can you?



What is the mode of inheritance of this disease?

- A. Autosomal recessive
- B. X-linked recessive
- C. Sex-influenced inheritance
- D. Maternal inheritance (cytoplasmic inheritance)

EG 2: Endosymbiosis again?? And again??

In a hypothetical unicellular eukaryote *Phagocytosis forlife*, it is found that there exists a secondary endosymbiont, such as a red alga, which is a photosynthetic unicellular eukaryote. Minimally, how many endosymbiotic events are necessary to produce this eukaryote *Phagocytosis forlife*?

- A. 1
- B. 2
- C. 3
- D. 4

EG 3: Basic Maths

Genes *A*, *B*, and *C* are each found on a different chromosome. What fraction of the offspring of *AabbCc* x *aaBbCc* will have the recessive *a*, dominant *B* and dominant *C* phenotype?

- A. $\frac{3}{16}$
- B. $\frac{4}{16}$
- C. $\frac{5}{16}$
- D. $\frac{6}{16}$

EG 4: Bzzzzzz

Periodical cicadas are found to have an especially long incubation period of more than 10 years, and are believed to have evolved during the Pleistocene Epoch, where the long incubation time helps them avoid random cold summers.

Curiously, however, all members of the population are developmentally synced and tend to emerge every 13 or 17 years, but never 12 or 16. Which of the following is the most likely explanation?

- A. It is an evolutionary relic of a certain timekeeping mechanism with no apparent evolutionary advantage.
- B. It is to prevent syncing of life cycle of the cicadas with their predator.
- C. It is for syncing the development of all the members of the population so that there is a higher chance of sexual reproduction.
- D. Their food source appears every 13 or 17 years.

EE 1: A Helping Hand

Altruism refers to behaviour that reduces the individual fitness of an animal but increases the fitness of other, usually closely related, individuals in the population.

Kin altruism describes behaviour that enhances a genetic relative's chances of survival and reproduction at the cost of the individual and can be explained by Hamilton's rule ($rB > C$). Reciprocal altruism describes behaviour that enhances another organism's chances of survival with the expectation that the recipient will act similarly in the future.

Three scenarios are given below.

- I. Meerkats live in large family clans. Meerkat sentinels, so-called because they watch for predators while other meerkat group members forage, could give off a warning call to alert its clan members. This would, however, expose the individual giving off the call to predation.
- II. Vampire bats live in colonies which often include unrelated individuals. A vampire bat can only survive for around 2 days without blood and is not guaranteed to find blood every night. Bats which fail to find blood can survive by 'begging' others for blood.
- III. Sterile worker bees are physiologically unable to reproduce. They, however, take on the job of processing incoming nectar, feeding the queen, as well as making and capping the honey. They may even sting aggressors approach the hive, killing itself in the process.

Arrange the above scenarios from the least to the most likely to lead to altruism.

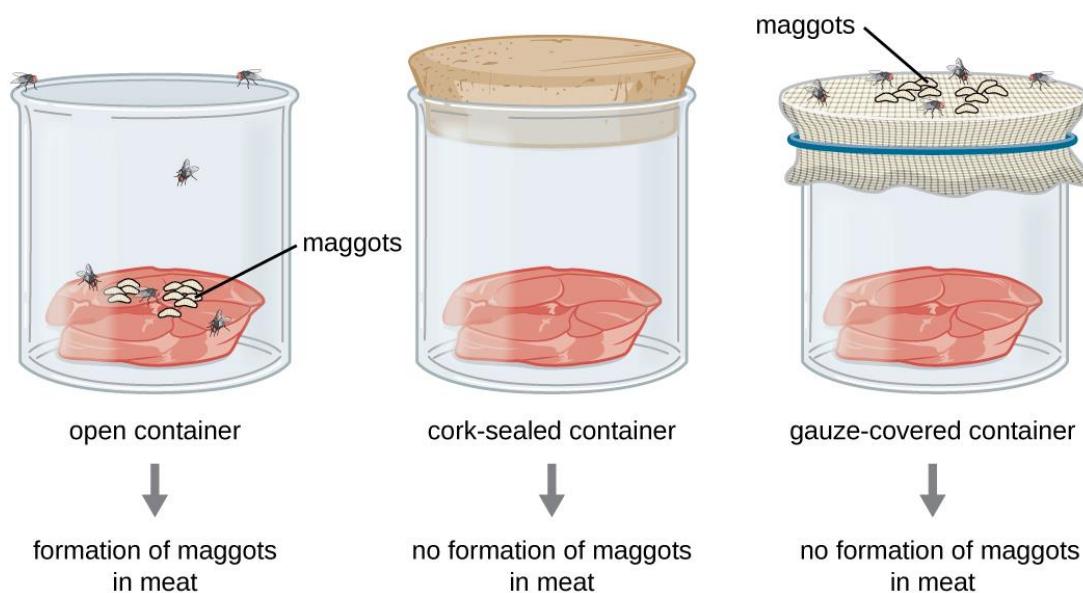
- A. I, III, II
- B. II, I, III
- C. III, I, II
- D. III, II, I

EE 2: Wormie

Maggots are the larvae of flies. Your friend observed that maggots were found crawling on meat that he left out in the open. He claimed that “*Maggots spontaneously generate from meat that is left out in the open air*”.

You disagreed with him and set up the following experiment to show that maggots do not spontaneously generate from meat that is left out in the open air.

You placed meat in either sealed containers, open containers, or containers covered with gauze and observed for the presence of maggots.



Indicate the purpose of the open container and cork-sealed container respectively in your experiment.

- A. Negative control, experimental group
- B. Negative control, positive control
- C. Experimental group, positive control
- D. Positive control, negative control

EE 3: Set in their ways

A fixed action pattern (FAP) is an innate and highly stereotyped set of actions, which occurs in response to a sign stimulus.

An example of a FAP is the mating behaviour of male stickleback fish. During their mating season, the ventrum of male sticklebacks turn red and they establish a territory. Male sticklebacks will invariably attack anything in their territory possessing a red belly. In this case, the red belly is the sign stimulus for the aggressive behaviour of the male stickleback.

Three phenomena observed in animals are listed below.

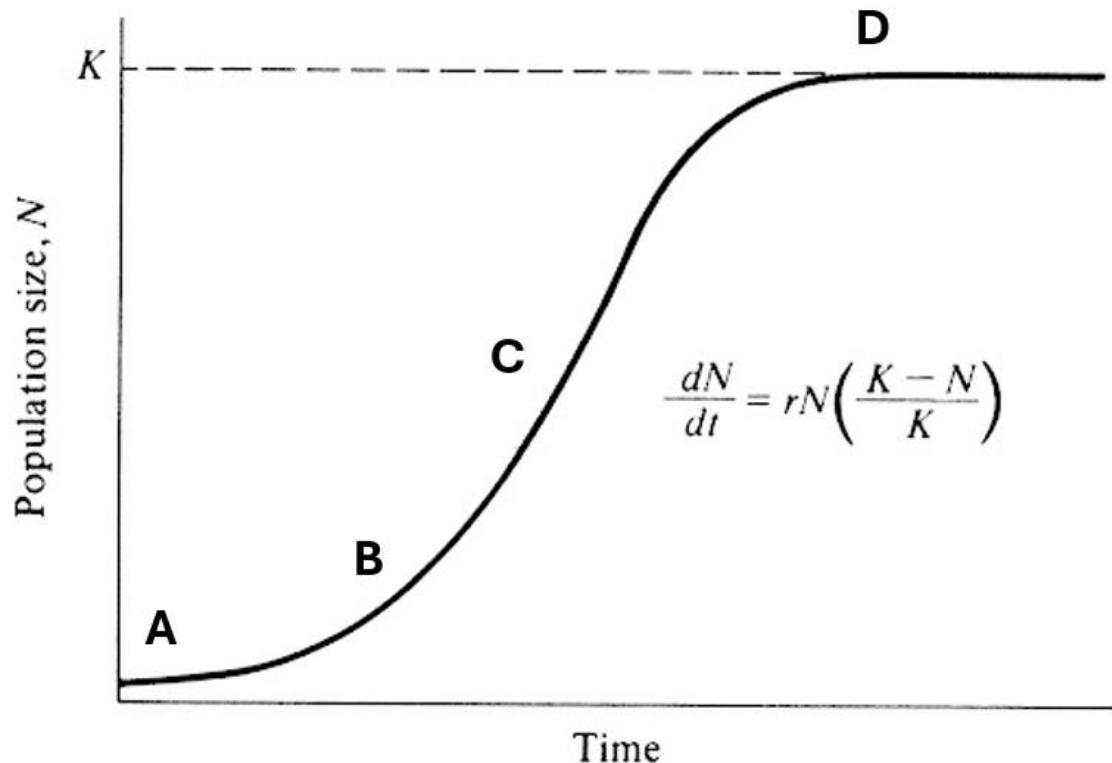
- I. A mother catches a toddler before it falls down.
- II. Moths spiral towards artificial light sources.
- III. A greylag goose rolling a nearby tennis ball into its nest.

Which of the above phenomena are examples of FAPs?

- A. III only
- B. I and II only
- C. II and III only
- D. I, II and III only

EE 4: Shortest question ever

At which point along the curve is the per capita growth rate the highest for the population?



MA 1: Insulin Man

The homeostasis model assessment of β -cell function ($HOMA - \beta$) equation can be used to gauge if pancreatic β -cell are functioning properly and secreting insulin as they are supposed to. The equation is as follows, with glucose being in mmol/L and insulin in mU/L:

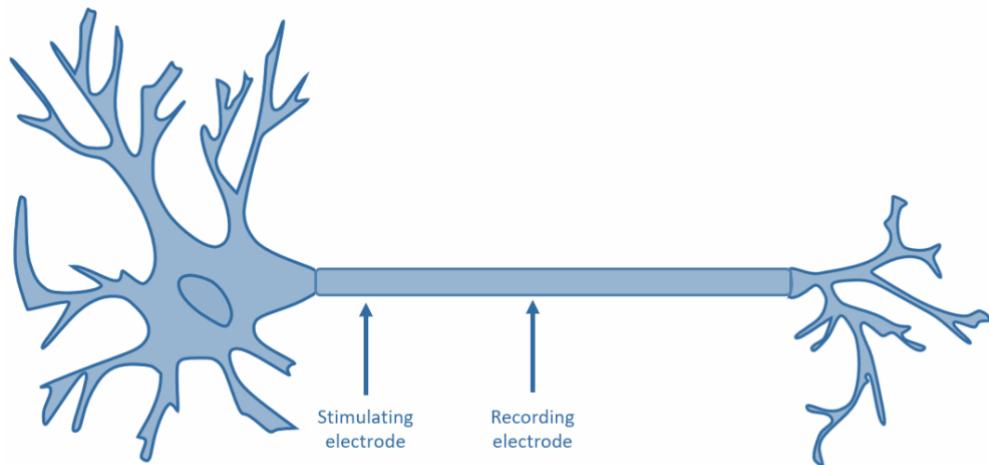
$$HOMA - \beta = \frac{20 \times \text{Insulin}}{\text{Glucose} - 3.5} \%$$

What is the HOMA- β value of someone with a fasting blood glucose level of 5000 $\mu\text{mol/L}$ and a fasting insulin level of 15 $\mu\text{U/dL}$?

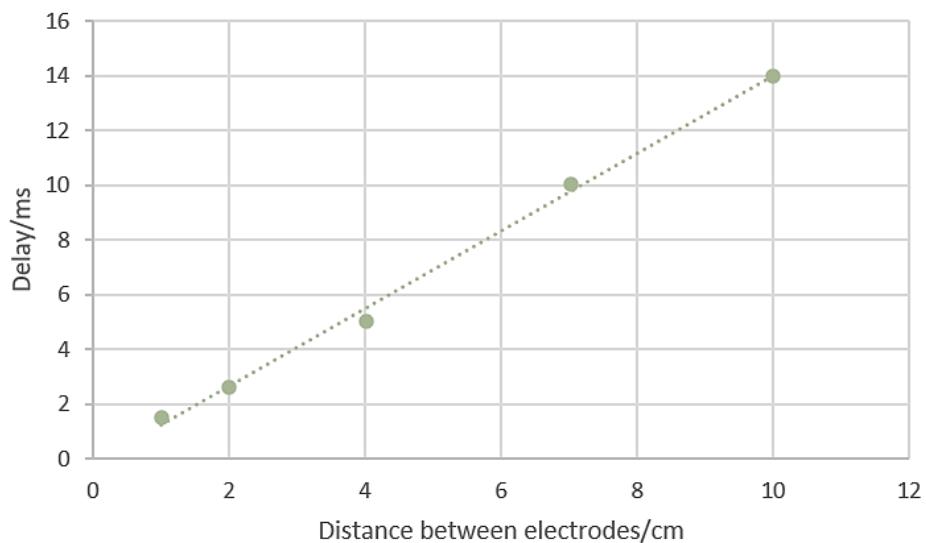
- A. 1%
- B. 2%
- C. 4%
- D. 5%

MA 2: Squidward

To investigate the rate of signal propagation in an axon, you attach stimulating and recording electrodes on an axon as seen in the diagram below and vary the distance between them to record the delay in the stimulus and response.



The graph below shows the results of the experiment.



Which of the following speed is the closest to the average speed of conduction in this axon?

- A. 0.7 m s^{-1}
- B. 1 m s^{-1}
- C. 7 m s^{-1}
- D. 10 m s^{-1}

MA 3: Don't be self-absorbed!

A new drug HX partially dissociates in water to form H^+ and X^- ions, with a pK_a of 5.7. The drug is absorbed through the cells lining the stomach and the small intestine by simple diffusion.

The pH values of different parts of the digestive system are given in the table below.

	pH
Stomach	1.5
Duodenum	6.0
Jejunum	5.4
Ileum	7.4

Using the pH values from the table, suggest the likeliest main absorption route for drug HX.

- A. Stomach
- B. Duodenum
- C. Jejunum
- D. Ileum

MA 4: Heart's a Ball

To predict the behaviour of and calculate parameters relating to different organs, we can reduce them to simpler shapes and make models based on these simplified structures. One such example is modelling the ventricles of the heart as spheres. If we model the left ventricle as a sphere, we can calculate the myocardial wall stress with the formula according to the Law of Laplace:

$$s = \frac{PR}{2t}$$

where:

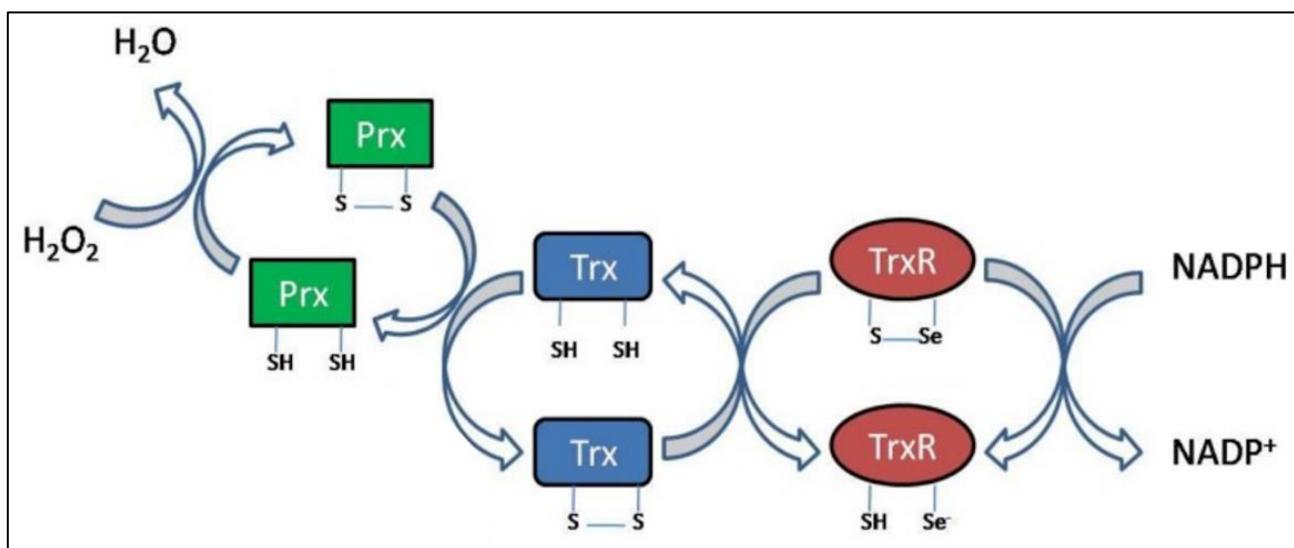
- P is the ventricular pressure,
- R is the ventricular radius,
- t is the maximum wall thickness.

Given that $t = 1.5$ cm, P is 90 mmHg and the end-diastolic volume is 150 mL, calculate s .

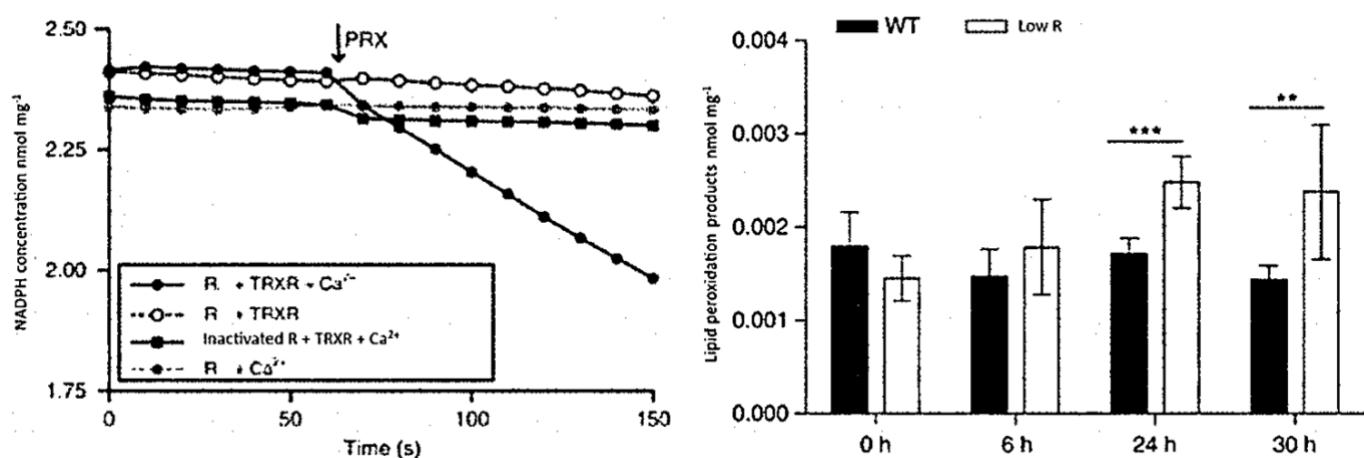
- A. 9 kPa
- B. 13.2 kPa
- C. 22.1 kPa
- D. 198 kPa

MP 1: It's hot in here

With climate change an undeniable reality, researchers are interested in understanding the effects of heat stress on all living things including plants. One such area is the regulation of redox reactions in the chloroplast. The figure below shows the mechanism of the Trx redox system in plants. Note that the reduction of hydrogen peroxide generates superoxide anions.



R is a novel modulator protein found in plants which may possibly play an important role in redox-related signalling. The figure below shows two experiments performed to investigate the role of **R** in plants. The line graph on the left shows the concentration of NADPH against time under various conditions, while the bar graph on the right shows the concentration of lipid peroxidation products in both wild-type (WT) plants and plants expressing low levels of **R** at different time intervals.



Based on the data, several statements were made regarding the role of **R** in plants.

- I. The action of **R** is dependent on Ca^{2+} .
- II. The depletion of **R** increases oxidative stress experienced by the plant.
- III. **R** increases the efficiency of oxidising **Prx**.
- IV. Depleting **R** will improve cyclic electron flow.

Which of the statements above are true?

- A. I, II, III
- B. I, II, IV
- C. I, III, IV
- D. II, III, IV

MP 2: A Tall Plant

Dr Lim is carrying out a physiological analysis of volume flow rate in the xylem at a fixed height throughout the day. She has already watered the plant with radiolabelled water for radioisotope tracing. As time passes towards noon, the volume flow rate measured strictly increases. Relative to the volume flow rate measured, what is the volume flow rate near the leaves at the top of the tree and near the roots respectively?

- A. Same, same
- B. Higher, lower
- C. Lower, higher
- D. Lower, lower

MP 3: Callous question; Don't be careless!

In tissue culture, a callus is a mass of irregularly shaped totipotent plant parenchyma cells. Callus cells can be found covering plant wounds or induced from explants *in vitro*. The culture medium is supplemented with plant hormones to induce the growth of the callus. You aim to investigate the effect of two plant hormones A and B on the growth of the callus. You cultured equal masses of plant callus taken from the same plant on culture medium and treated each culture according to the following table. The results are shown in the table.

Treatment	Concentration of hormone added/a.u.		Size of root (Normalised)	Size of shoot (Normalised)
	Hormone A	Hormone B		
1	0.5	50	1	0
2	5.0	0.0	0	0
3	10.0	5.0	0	1
4	0.0	50	0	0
5	5.0	50	Growth with no differentiation	

Based on the results, you wrote down several conclusions.

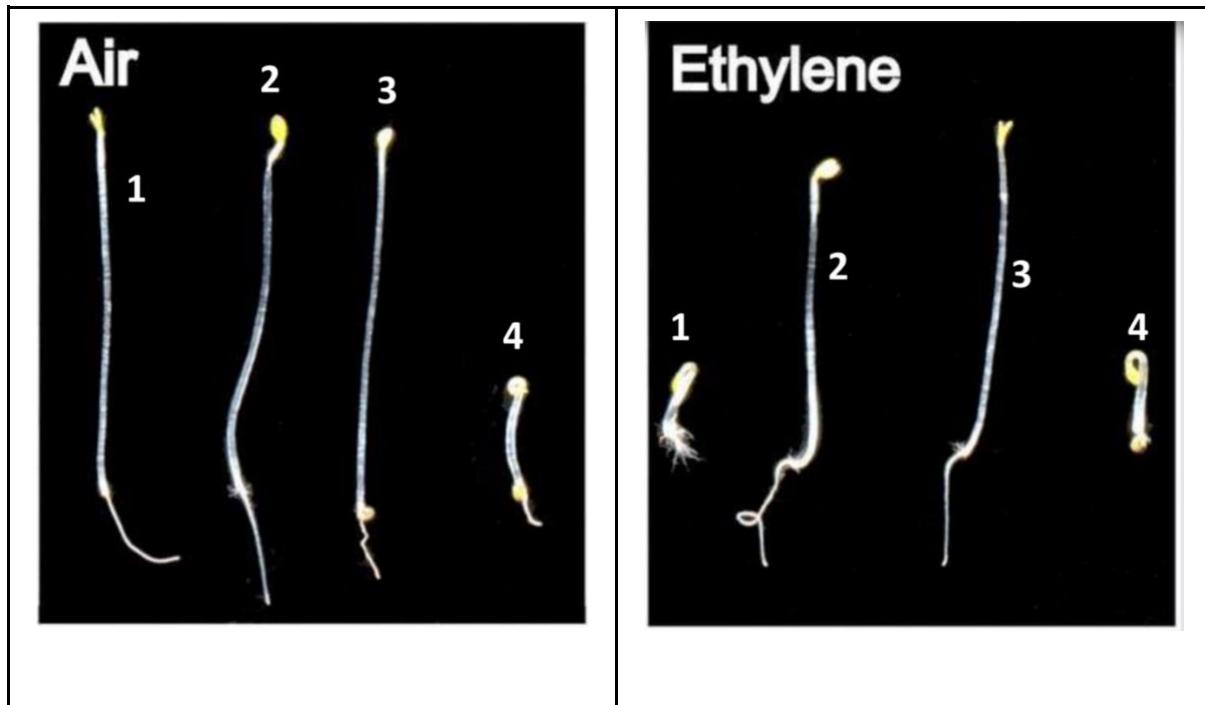
- I. Both hormones A and B are required for cell division of the callus.
- II. A high ratio of hormone A : hormone B results in differentiation of the callus cells to form the root.
- III. Hormone B is required for the differentiation of callus cells.
- IV. Transferring the callus cells from treatment 3 to a medium subjected to treatment 1 can transform them into plantlets.
- V. The roots in treatment 1 are genetically identical to the shoots in treatment 3 but are genetically different from the mass in treatment 5.

Which of the above conclusions are valid based on the results?

- A. I, III, V only
- B. I, III, IV only
- C. I, II, IV, V only
- D. I, II, III, V only

MP 4: Plants breathe too!

Four different *Arabidopsis* seedlings were grown in the dark, of which one is an ethylene-insensitive mutant; one is a constitutive-triple response mutant; another is an ethylene-receptor mutant, and the other is wild-type (labelled 1-4). The four mutants are grown under both normal air conditions and in the presence of ethylene.

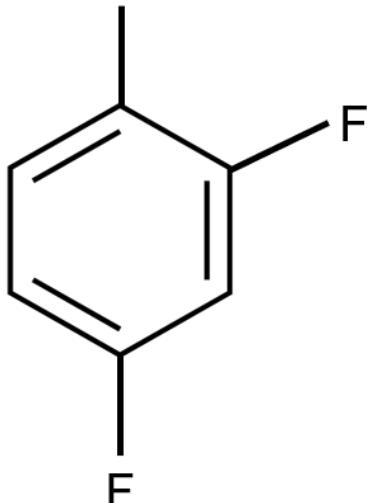


Match the mutants to the labelled seedlings in the diagram above.

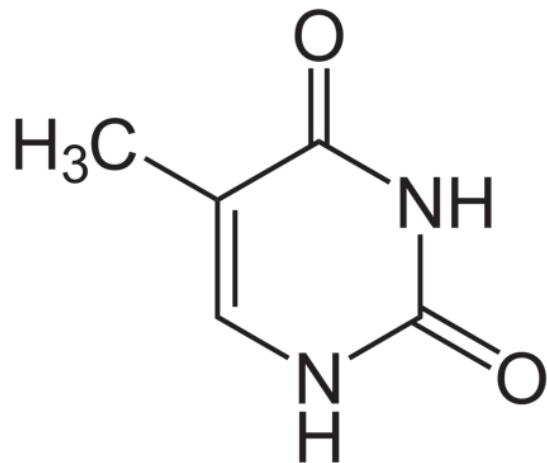
	1	2	3	4
A.	Ethylene-receptor mutant	Ethylene-insensitive mutant	Wild type	Constitutive-triple response mutant
B.	Constitutive-triple response mutant	Ethylene-receptor mutant	Ethylene-insensitive mutant	Wild type
C.	Wild type	Ethylene-insensitive mutant	Constitutive-triple response mutant	Ethylene-receptor mutant
D.	Wild type	Ethylene-insensitive mutant	Ethylene-receptor mutant	Constitutive-triple response mutant

MC 1: 2,4-difluorotoluene

Scientists have attempted to synthesise nitrogenous bases other than the canonical four (A, T, C, G) in the lab. One analogue synthesised is 2,4-difluorotoluene (X). X base pairs with adenine and behaves like the canonical nitrogenous bases. The structure of X and thymine can be seen below.



Structure of 2,4-difluorotoluene



Structure of thymine

How many carbon atoms are there in a single-stranded DNA triplet XXT?

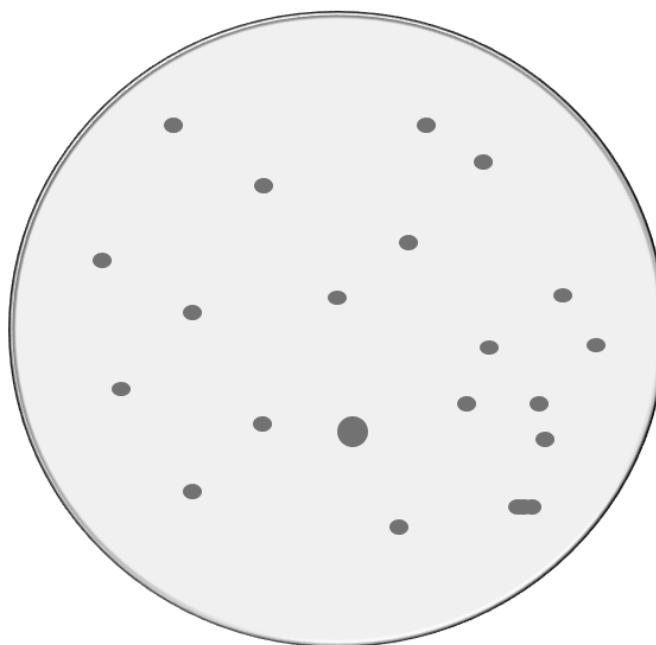
- A. 15
- B. 19
- C. 20
- D. 34

MC 2: Cultured in Biology

Colony-forming units (CFUs) is a unit which estimates the number of microbial cells in a sample. To investigate the amount of bacteria in a sample X, you performed the following dilution steps:

1. Transfer 40 μ L of the sample solution into nutrient medium to make up 10mL and mix.
2. Transfer 0.5mL of the above solution into 9.5mL of nutrient medium and repeat this five more times.
3. Plate 3mL of the resultant solution on nutrient-poor agar and incubate at 37°C overnight.

The results are seen below.

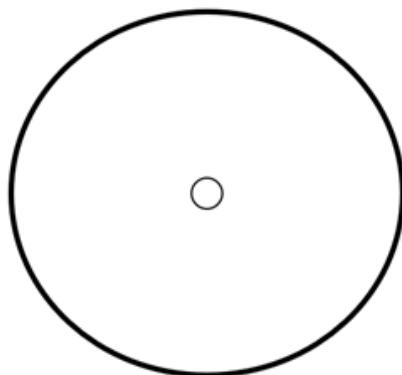


Calculate the approximate number of colony forming units (CFUs) per mL in Sample X.

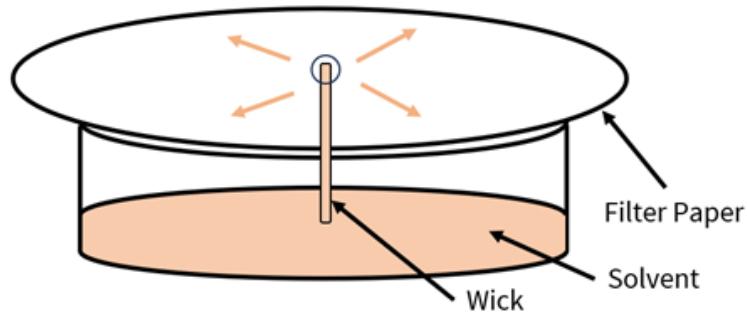
- A. 5.33×10^9 CFUs
- B. 3.20×10^{10} CFUs
- C. 5.33×10^{10} CFUs
- D. 1.07×10^{11} CFUs

MC 3: Poly-Poly

A type of chromatography is radial chromatography which is similar to thin-layer chromatography. The solvent is drawn up the wick and travels radially outwards through the filter paper.



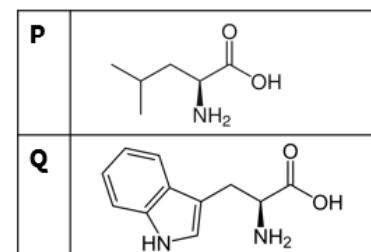
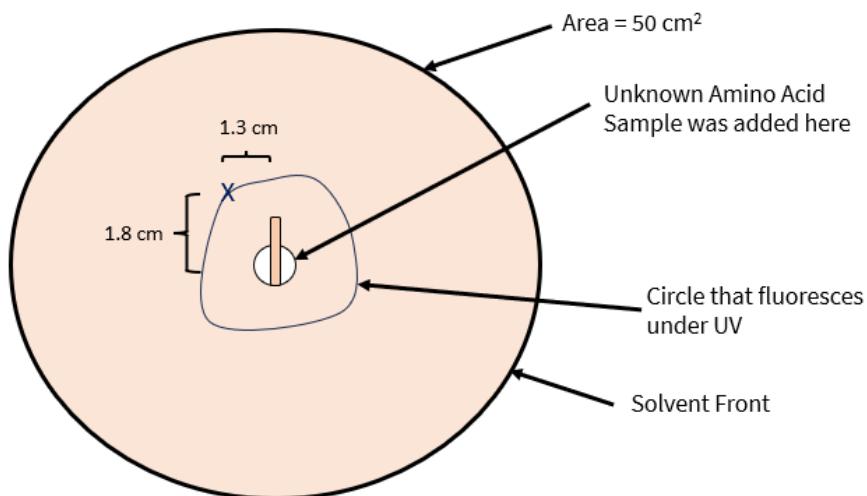
Top View



Side View

To identify an unknown amino acid, you added a sample to the middle and allowed chromatography to occur until the solvent front (ethanol) reaches the circumference of the filter paper. Then you observe the amino acid by UV light which causes a circle to fluoresce on the paper. The area of the round filter paper is 50 cm^2 .

You know that the unknown amino acid is either amino acid P or Q as seen in the table.



★ Medium

Cell Biology



Calculate the R_f value of the amino acid and identify the amino acid.

- A. 0.56, P
- B. 0.56, Q
- C. 0.72, P
- D. 0.72, Q

MC 4: Cell division = Multiplication

Microtubules are made of $\alpha\beta$ tubulin heterodimers. Suppose some $\alpha\beta$ tubulin heterodimers, which are equidistant from the microtubule-organising centre (MTOC) and the chromosomes which it is attached to, are fluorescently tagged in metaphase. Shortly after the beginning of anaphase, the fluorescently tagged $\alpha\beta$ tubulin heterodimers are found closer to the chromosome than the MTOC.

Which of the following explanations are most likely?

- A. Most of the depolymerisation of $\alpha\beta$ tubulin heterodimers occurs near the chromosome
- B. Microtubular breaks cause unexpected shortening of the kinetochore microtubules
- C. Most of the depolymerisation of $\alpha\beta$ tubulin heterodimers occurs near the MTOC
- D. Random polymerisation and depolymerisation rearranges the fluorescently tagged $\alpha\beta$ tubulin heterodimers within the kinetochore microtubules

MG 1: Beta

Beta-thalassaemia is a blood disorder caused by mutations to the HBB gene, which is inherited in an autosomal recessive fashion. The three alleles of HBB produce normal beta-globin (β), partially functioning beta-globin (β^+) and no functional beta-globin (β^0).

In order to study the frequency of beta-thalassaemia on the island of *Biotropica*, Claire conducted a study on 10 000 individuals on the island. Assume that the population is in Hardy-Weinberg equilibrium. The number of heterozygotes for the different alleles are seen in the table below:

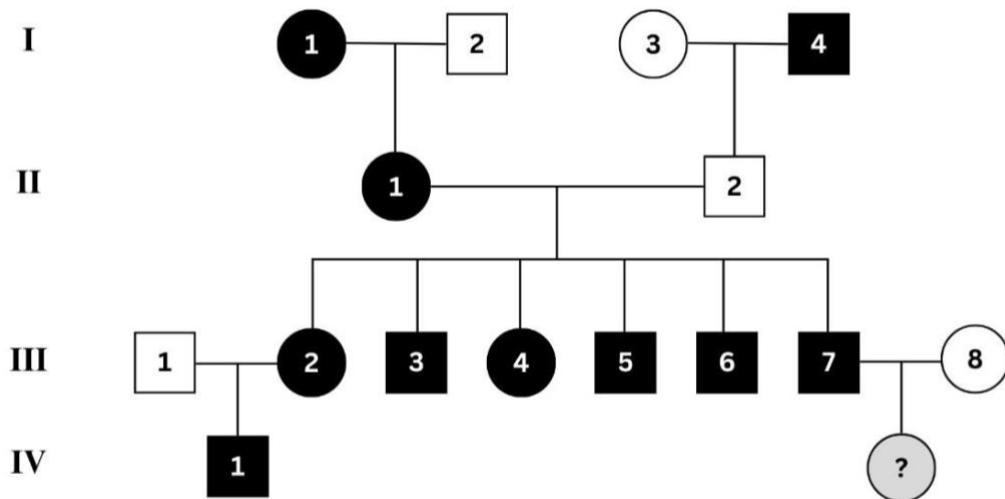
Genotype	Number of Individuals
β/β^+	1700
β/β^0	850
β^+/β^0	100

What is the frequency of the β^+ allele?

- A. 0.01
- B. 0.025
- C. 0.05
- D. 0.10

MG 2: You get one, everyone gets one

A rare disease caused by a point mutation is found in only Individuals I-1 and I-4 in Generation I and is passed down multiple generations of a Canadian family as shown below.



What is the most likely probability that the female offspring of III-7 and III-8 is afflicted with the disease?

- A. 0
- B. 0.25
- C. 0.5
- D. 1

MG 3: The *vaL* operon

The *vaL* operon is a novel operon discovered in some bacterial species. The *vaL* operon is made up of five sequences of DNA: the regulatory gene, promoter, operator, and two genes that code for enzymes A and B. Regulation of expression of the *vaL* operon is dependent on the presence of *vaL*.

You conducted an experiment with wild-type and mutant bacterial cells with the *vaL* operon in the presence or absence of *vaL*. Each mutant bacterial cell has a different loss-of-function mutation in one of the five genes that constitute the operon. To assess the activity of the two enzymes in the bacterial cells, you make use of the colourless chromogenic substrate vermonin. Enzyme A converts vermonin into a blue compound, while Enzyme B converts vermonin into a yellow compound. The results are shown below.

	Colour	
	Absence of <i>vaL</i>	Presence of <i>vaL</i>
WT	?	?
Mutant 1	Yellow	Colourless
Mutant 2	Green	Green
Mutant 3	Colourless	Colourless
Mutant 4	Green	Green
Mutant 5	Blue	Colourless

You conducted another experiment on an unknown mutant 6 with the following results:

	Colour	
	Absence of <i>vaL</i>	Presence of <i>vaL</i>
Mutant 6	Blue	Blue

Several statements were made regarding the mutants and the *vaL* operon.

- In the presence of *vaL*, the colour of the WT cells should be green.
- Mutant 1 has a mutation in enzyme A.
- Mutant 3 has a mutation in the promoter.
- Mutant 4 definitely has a mutation in the operator.
- Mutant 6 could contain a loss-of-function mutation in both the regulatory gene and enzyme B.

★ Medium

Genetics



Which of the above statements are true?

- A. I, II, IV
- B. I, IV, V
- C. II, III, IV
- D. II, III, V

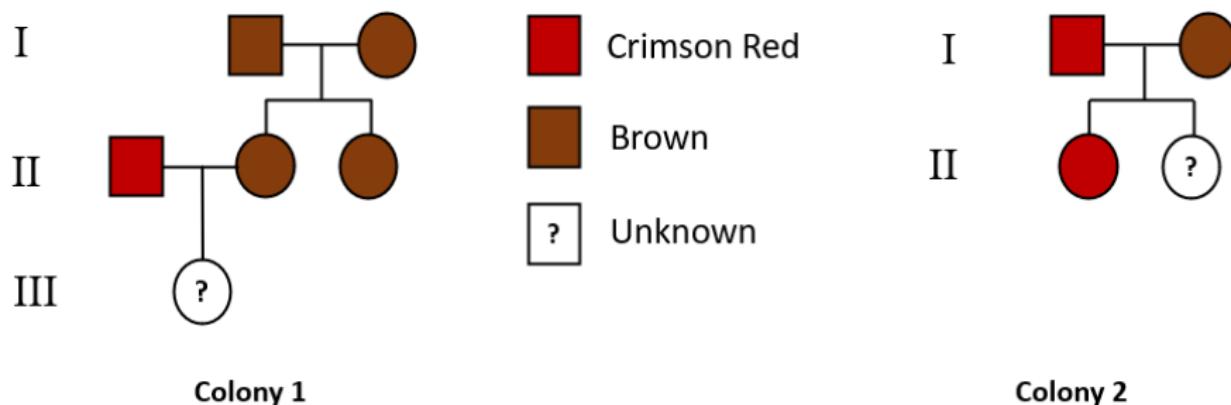
MG 4: I hate ants

Ants are insects from the order Hymenoptera and are eusocial organisms, performing specialised roles in their colony. Females are diploid and may either be a fertile queen or infertile workers, while males are haploid and develop into fertile drones. The development of the female into a queen or worker is dependent on their diet. An unfertilised egg from the queen develops into a male, while a fertilised egg will develop into a female.

In ants, the allele *thoraci* codes for the Thoraci enzyme. The Thoraci enzyme converts a colourless precursor into an intermediate which is then converted to a red pigment by a different enzyme. The red pigment is deposited on the thorax, and once it accumulates to a sufficient concentration, it turns the thorax crimson red. If insufficient red pigment is deposited, the thorax remains brown.

The other allele, *redless*, codes for the anti-Thoraci enzyme which converts the colourless precursor into another colourless compound which cannot be converted by Thoraci. The rate of this conversion by anti-Thoraci is faster than the rate of conversion of the colourless precursor into the intermediate by Thoraci.

The diagram below shows the pedigrees of two colonies of ants. Female I-2 of colony 1 is known to be homozygous.



Several statements were made regarding the ants and the two colonies.

- I. Crimson red is the recessive phenotype.
- II. There is a 100% chance that II-2 of **colony 1** is homozygous.
- III. There is a 25% chance or less that III-1 of **colony 1** will be crimson red.
- IV. III-1 of **colony 1** shares 50% of its genes with I-1.
- V. If I-1 and I-2 of **colony 2** had another progeny, the probability that the progeny is a brown male is 25.0%.

★ Medium

Ecology



Which of the above statements are true?

- A. I, II, IV only
- B. I, III, V only
- C. II and III only
- D. II and IV only

ME 1: Chalky Business

The oceanic carbon cycle is made up of several processes exchanging carbon with the atmosphere and distributing it throughout the oceans.

The following equations describe parts of the oceanic carbon cycle:

- $\text{CO}_2 \text{ (dissolved)} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$
- $\text{HCO}_3^- \rightleftharpoons \text{H}^+ + \text{CO}_3^{2-}$
- $\text{Ca}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{CaCO}_3$

The carbonate saturation horizon is a dissolution boundary, below which the dissolution of calcium carbonate is thermodynamically favoured. The carbonate compensation depth is the depth in the ocean at which the rate of supply of calcium carbonate is equal to the rate of dissolution.

Three statements are made below.

- Calcareous depositions can only accumulate between the carbonate saturation horizon and the carbonate compensation depth.
- With the rise in atmospheric carbon dioxide levels, calcareous species will be able to survive in lower depths.
- Temperature, pressure and salinity contribute to the increase in calcium carbonate solubility at lower depths.

Which of the above statements are **false**?

- I and II only
- I and III only
- II and III only
- I, II and III

ME 2: Hey mate!

You are a zookeeper that takes care of four different animals: Southern yellowjacket (*Vespula squamosa*), White-handed Gibbon (*Hylobates lar*), Chimpanzee (*Pan troglodytes*), and Common marmoset (*Callithrix jacchus*). You are interested in the mating behaviours of these four animals. You first marked each organism in the enclosure with a unique tag. You then observed the number of matings between the male animals (A-J) and female animals (K-T) during Week 1 and Week 4. You were recording down the data when the papers containing your data flew away, causing you to not know which paper belongs to which animal.

The diagram below shows one of the papers containing the data of one of the animals. You noticed that the number 16 is clustered together in the data of both weeks, so you highlighted all instances of the number 16 on the paper.

	A	B	C	D	E	F	G	H	I	J
K	22	15	19	27	17	20	21	14	23	13
L	12	17	18	17	13	13	19	16	12	15
M	14	20	14	12	21	11	15	23	14	13
N	18	15	16	12	19	16	12	17	18	20
O	13	19	13	13	14	15	21	14	12	21
P	23	17	21	21	14	19	15	15	13	16
Q	16	16	16	17	13	16	21	14	12	20
R	16	16	16	19	20	23	17	21	17	14
S	16	16	16	13	17	23	22	20	12	17
T	14	20	14	20	18	12	18	13	15	17

Week 1

	A	B	C	D	E	F	G	H	I	J
K	22	15	19	27	17	20	21	14	23	13
L	12	15	13	21	18	15	15	12	12	16
M	14	14	12	16	16	16	16	19	21	13
N	21	14	12	16	16	16	16	21	15	21
O	15	15	18	16	16	16	16	17	21	16
P	21	14	12	16	16	16	16	12	12	22
Q	17	21	17	18	17	23	12	16	21	23
R	22	20	12	13	20	12	21	18	15	19
S	20	12	17	16	14	21	12	19	18	18
T	18	20	14	20	16	20	14	13	15	17

Week 4

★ Medium

Ecology



Which animal does the data most likely belong to?

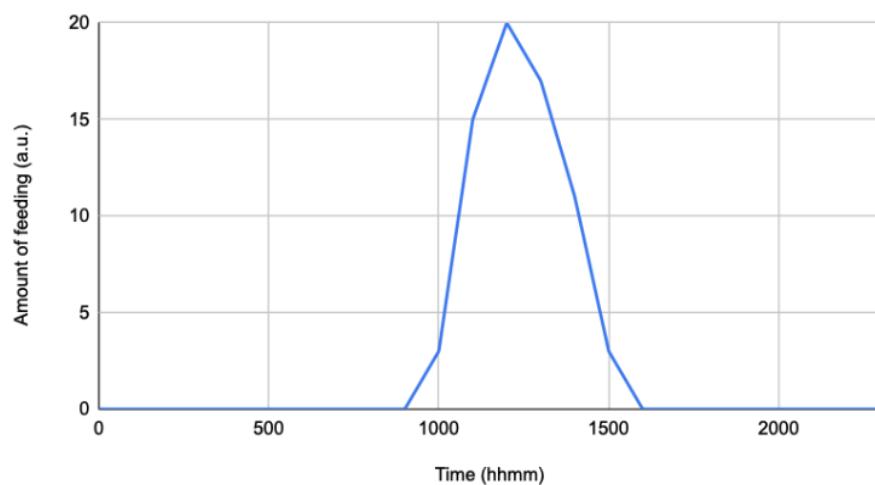
- A. Southern yellowjacket (*Vespula squamosa*)
- B. White-handed Gibbon (*Hylobates lar*)
- C. Chimpanzee (*Pan troglodytes*)
- D. Common marmoset (*Callithrix jacchus*)

ME 3: Overcrowded school canteen

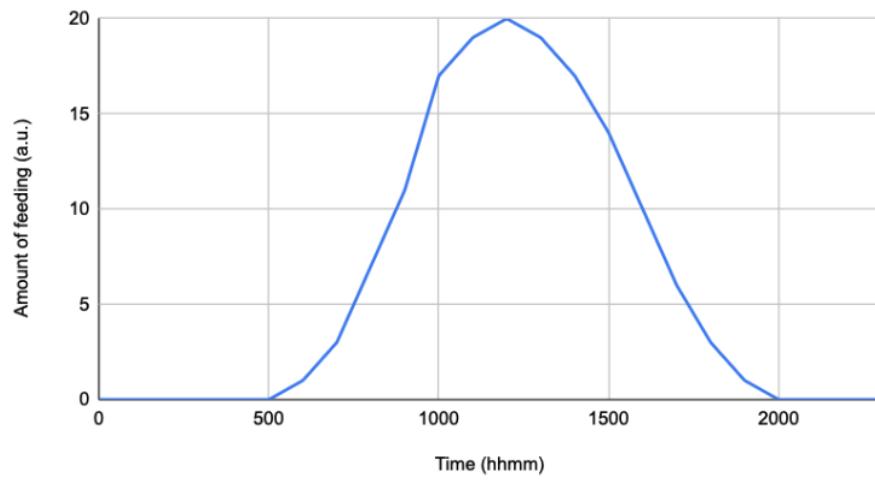
Two monophyletic species of birds, *Biologia major* and *Physica major*, both consume the same source of food: the sweet, sweet nectar of the *Schola canteen* flower. The *Schola canteen* flower produces nectar all the time, but it can only accommodate one bird per flower at any one time.

In isolation, and with the same environmental conditions, both species of birds exhibit a feeding pattern as shown in the figures below.

Biologia major feeding pattern



Physica major feeding pattern



A population of *Biologia major* and a population of *Physica major* simultaneously migrate into a newly formed habitat with very limited *Schola canteen* flowers, such that even if only one of the populations were introduced to the species, there would not be sufficient nectar for every individual.

Two physics and two biology students each made a statement regarding the two birds *Biologia major* and *Physica major*.

- I. If neither species competitively displaces their feeding pattern, *Biologia major* is more likely to be competitively excluded than *Physica major*.
- II. *Biologia major* is more likely than *Physica major* to competitively displace its feeding pattern than *Physica major*.
- III. Suppose one species competitively displaces its feeding pattern. If the other species is completely culled, the first species will likely revert back to its natural feeding pattern.
- IV. A second newly formed habitat is found far away from the first, and both species are introduced simultaneously. The effect on both species' feeding patterns could be different between the two habitats.

Which of the above statements are true?

- A. I, II, IV only
- B. I and III only
- C. I, III, IV only
- D. III and IV only

ME 4: The Emoji Question

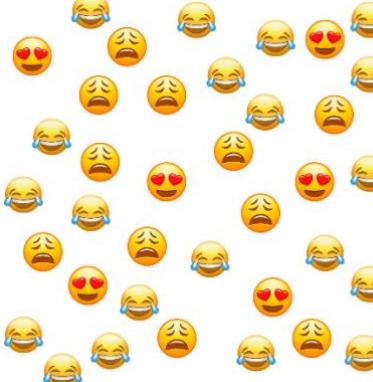
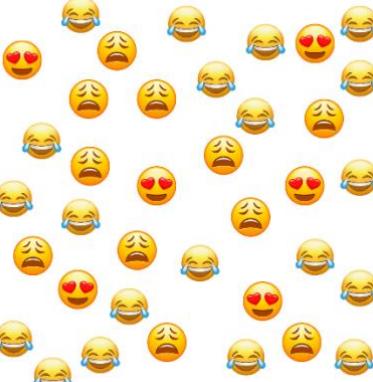
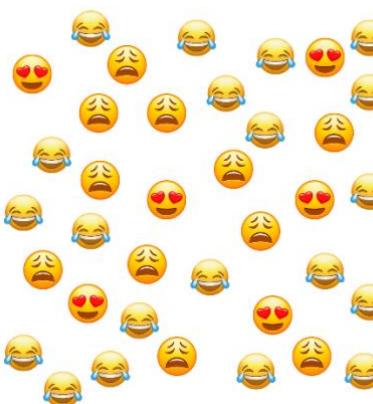
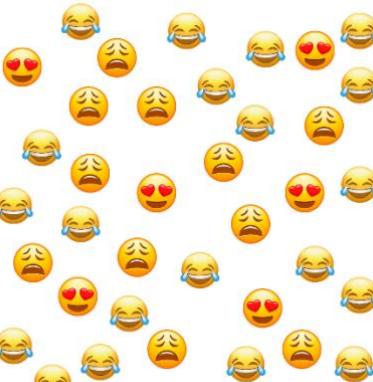
Six species, each represented by an emoji, are the only species that live in a fictitious habitat. The habitat is prone to occasional destruction due to a nearby volcano that resets parts of the habitat into secondary succession.



100 years ago, the government decided to fund an ecological experiment. The habitat was divided into three identical zones, and barriers were placed to ensure no species movement between zones.

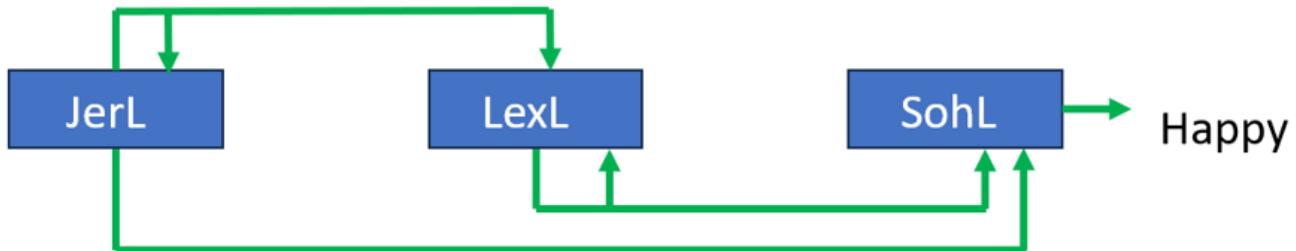
	Treatment
Zone 1	No treatment. The volcano continues to occasionally destroy the habitat and kill some living species.
Zone 2	Preventive measures against volcanic eruptions to completely avoid future damage done on the habitat. No more living species are killed by the volcano.
Zone 3	The officer in charge of zone 3 hates emojis and sets the entire zone on fire at the start of the experiment. This kills all the living species.

Given that there are exactly three trophic levels, and each consumer only preys on species in the trophic level directly below its own, which of the following options show the most likely species distribution diagrams for each zone now?

	Zone 1	Zone 2	Zone 3
A.			
B.			
C.			
D.			

HA 1: Live Laugh Love

Dr Pahari is investigating the interactions between 3 genes in a genetic pathway in *Drosophila melanogaster*. Above is a diagram of a gene circuit where *JerL*, *LexL* and *SohL* are genes that code for transcription factors Live, Laugh and Love respectively.



Several statements were made regarding this system.

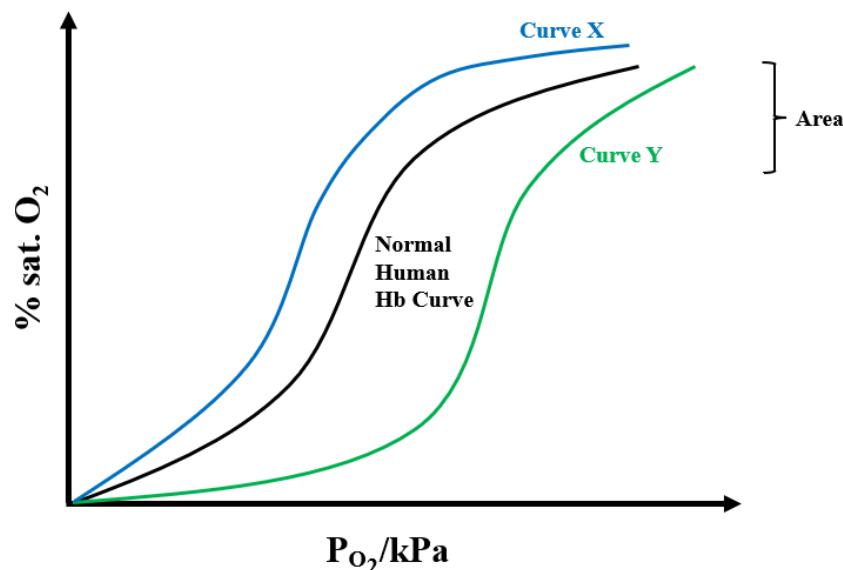
- I. The following system exhibits bistability.
- II. Exogenous introduction of Laugh leads to sustained expression of Love.
- III. The system acts via *trans* regulatory elements (i.e. genes can be found on different chromosomes and can act via long distances).
- IV. Exogenous introduction of Love will lead to a sustained happiness.

Which of the above statements are true?

- A. II only
- B. I and III only
- C. I, II, and III only
- D. I, II, III, IV

HA 2: Breathe in and out

An oxygen-dissociation curve illustrates the differences in affinity of haemoglobin to oxygen at different oxygen levels. The diagram below shows several oxygen-dissociation curves, as well as a normal human haemoglobin curve (black).



Lily made several statements regarding the oxygen-dissociation curves in the diagram above.

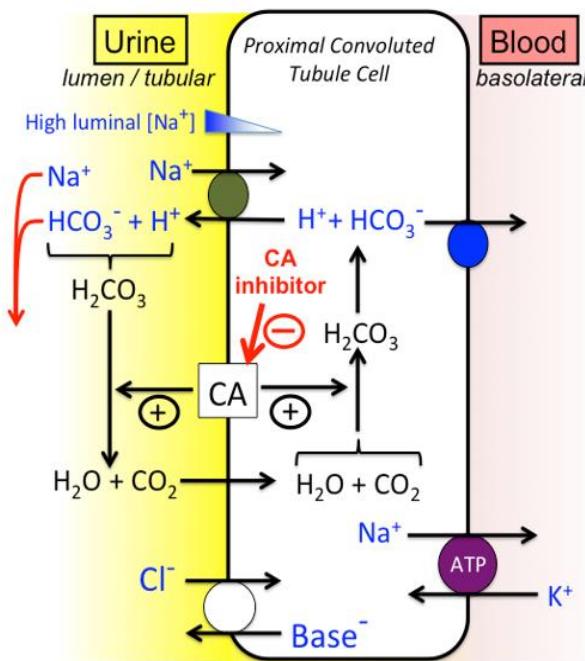
- The shape of the normal human haemoglobin curve is due to the presence of strong covalent bonds between the four subunits of haemoglobin allowing the subunits to increase in affinity to oxygen upon the binding of oxygen to one subunit.
- Increasing the red blood cell count of humans will shift the normal curve to resemble curve Y.
- Hypocarbia (low levels of carbon dioxide in the body) will shift the normal curve to curve X.
- The “Area” indicated by the parenthesis on the normal Hb curve indicates the O_2 released to the exercising tissues.
- Animals with curve Y are expected to have a higher specific metabolic rate than those with curve X.

Which of the above statements are true?

- I and III only
- II, IV, V
- III and V only
- I, II, III, IV

HA 3: I want to pee

Carbonic anhydrase is an enzyme that catalyses the interconversion of H_2CO_3 and $\text{CO}_2 + \text{H}_2\text{O}$ in humans. Carbonic anhydrase can be inhibited by inhibitors such as acetazolamide and methazolamide. The diagram below shows the role of carbonic anhydrase in the proximal convoluted tubule of the kidneys.



Several statements regarding the effects of acetazolamide and methazolamide are made.

- I. They decrease the pH of urine.
- II. Urine produced contains more Na^+ and water.
- III. They can help reverse the effects of blood acidosis.
- IV. More K^+ is lost from the blood.
- V. They promote formation of calcium phosphate stones.

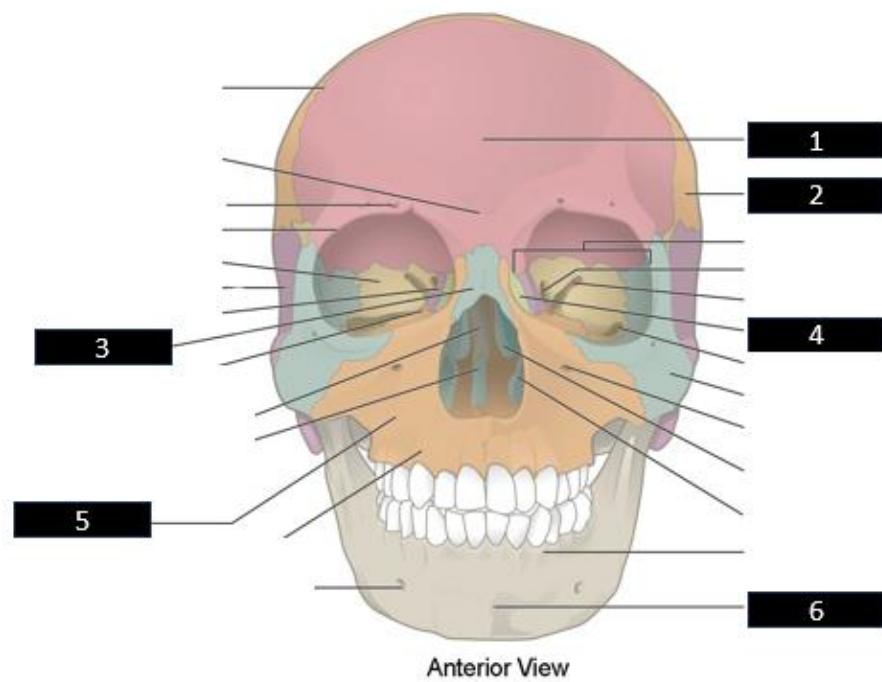
Which of the above statements are true?

- A. I, II, III only
- B. I and V only
- C. II, IV, V only
- D. III and IV only

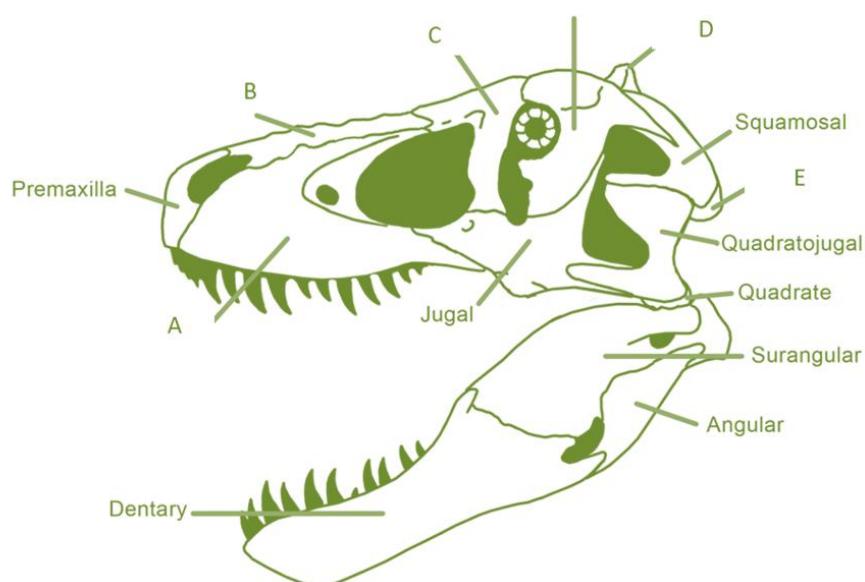
HA 4: T-Rex Rexsurrection

The *Tyrannosaurus Rex* (*T. Rex*) is a theropod that lived in what is now western North America. It lived about 90 to 66 million years ago, at the end of the Late Cretaceous. Despite the fact that our lineage diverged from that leading to the dinosaurs a long time ago, vertebrate homologies do exist, especially in cranial morphology and hence parts of the human skull can be used to identify homologous structures in *T. rex*.

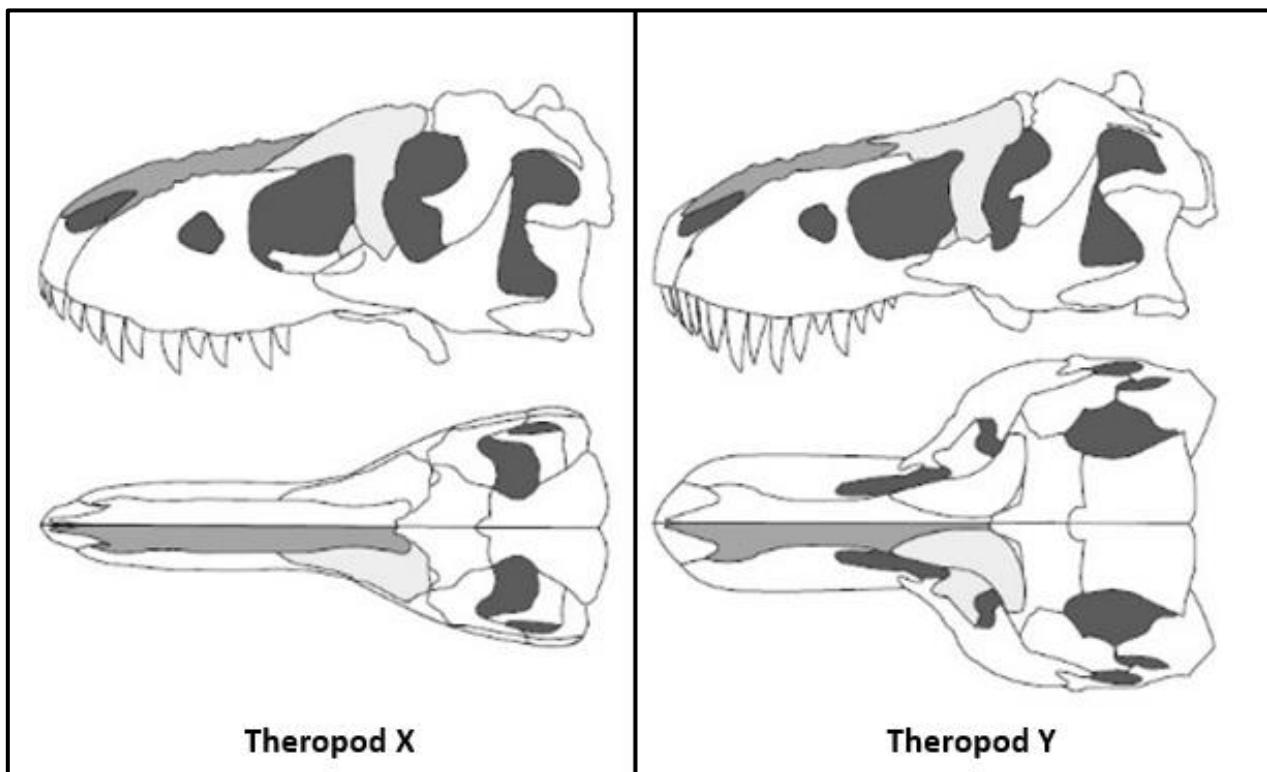
The diagram below shows the human skull with several labelled structures (1-6).



The diagram below shows the skull of a *T. rex* with several labelled structures (A-E).



The skulls of two different theropods are also seen below.



Lionel made several statements below.

- I. Structure 1 is homologous to Structure C.
- II. Structure 2 is homologous to Structure E.
- III. Structure 3 is homologous to Structure B.
- IV. Structure 6 is homologous to Structure A.
- V. Theropod Y has a higher bite force than theropod X.

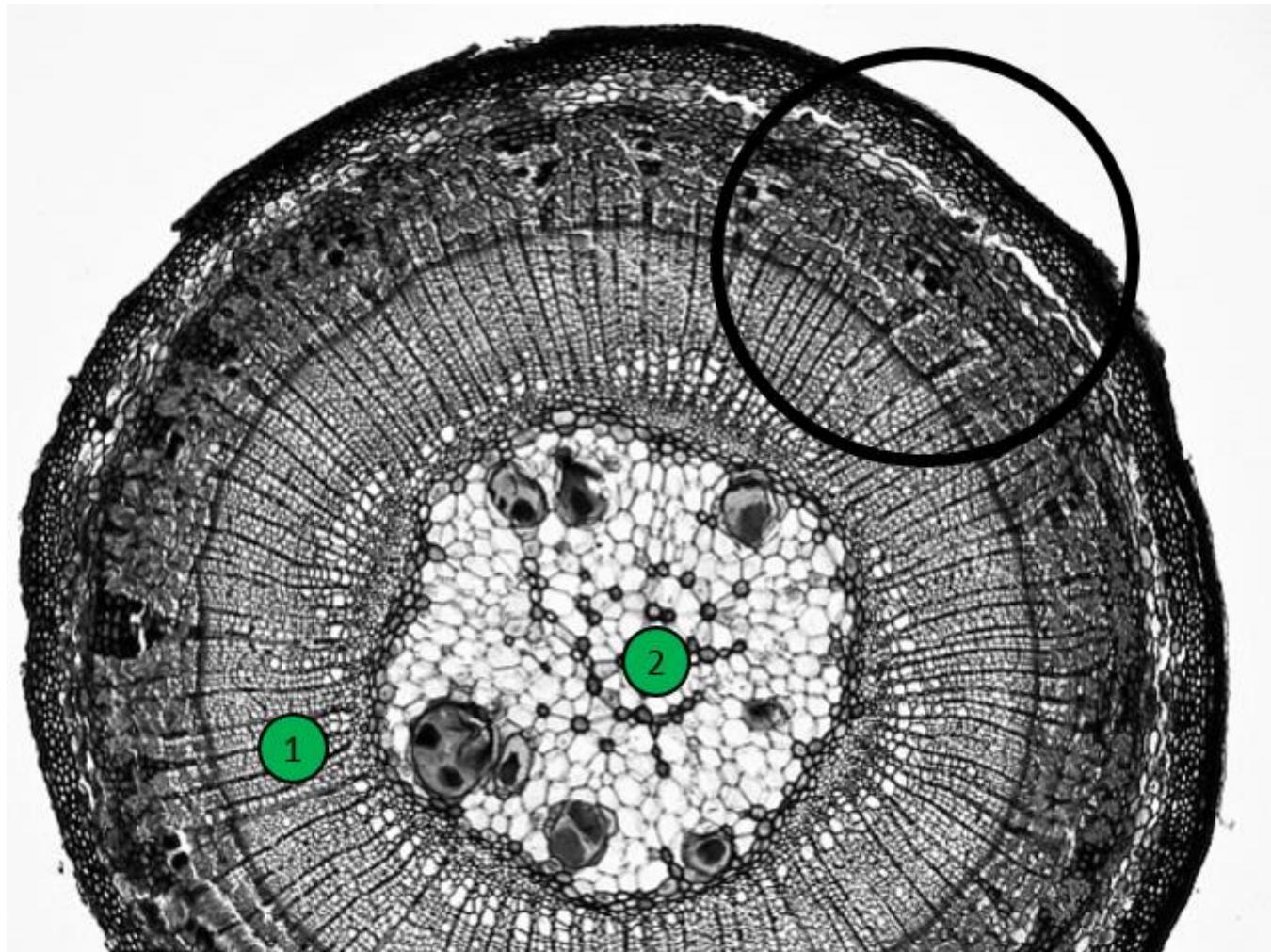
Which of the above statements are true?

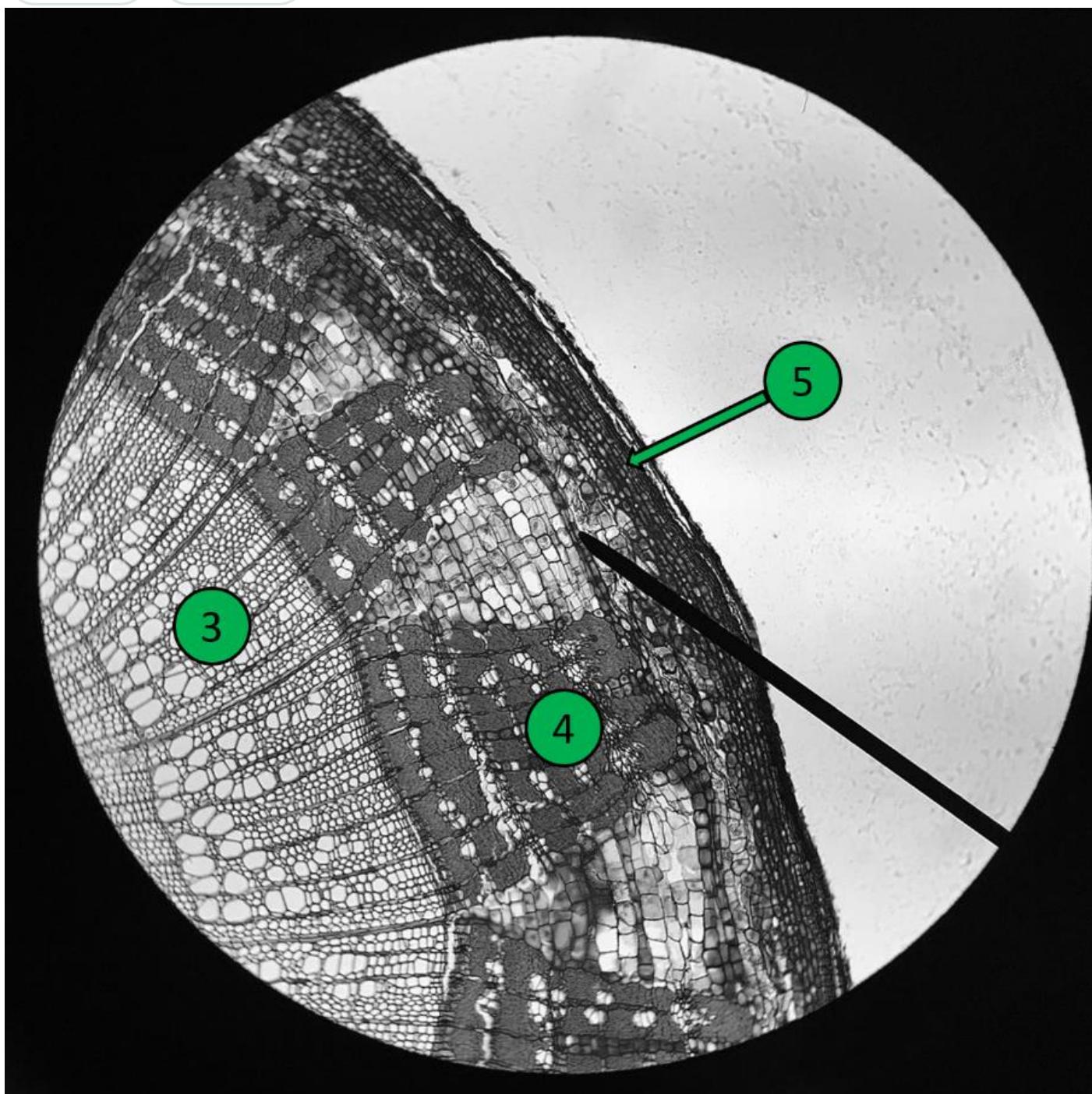
- A. I, II, IV only
- B. I and IV only
- C. III and V only
- D. I, II, III, and V only

HP 1: Cyber Green

SYBR Green I stain is a dye that intercalates with DNA and can be used to visualise DNA. The stain fluoresces under UV light, allowing for identification of the presence of DNA.

The photomicrographs below show a partial section of the same stem of an angiosperm. The circled section in the first cross section is shown more clearly in the second photomicrograph. Five parts of the stem are marked with numbers.





If the stem section was stained with SYBR Green I stain, how many of the five marked parts will fluoresce?

- A. 1
- B. 2
- C. 3
- D. 4

HP 2: Electrochemistry of life

The light-dependent reactions in photosynthesis are electrochemical reactions carried out by electron carriers in the chloroplasts. Suppose reducin is added, which disrupts the electron transfer. What is the earliest point at which electron transfer along the electron transport chain is halted in physiological standard state and standard state respectively?

Reduction equation	Redox potential at physiological standard state, E'^o/V	Redox potential at standard state, E^o/V
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	+0.82	+1.23
$P680^+ + e^- \rightarrow P680$	+0.9	+0.9
$P680^+ + e^- \rightarrow P680^*$	-0.8	-0.8
$PQ(ox) + e^- \rightarrow PQ(red)$	0	0
$b_6f(ox) + e^- \rightarrow b_6f(red)$	+0.2	+0.2
$PC(ox) + e^- \rightarrow PC(red)$	+0.37	+0.37
$P700^+ + e^- \rightarrow P700$	+0.4	+0.4
$P700^+ + e^- \rightarrow P700^*$	-1.3	-1.3
$Fd(ox) + e^- \rightarrow Fd(red)$	-0.42	-0.42
$NADP^+ + 2e^- + H^+ \rightarrow NADPH$	-0.32	-0.11
$Reducin(ox) + e^- \rightarrow Reducin(red)$	-1.0	-1.0

	Physiological standard state	Standard state
A.	Reduction of $Fd(ox)$ by $P700^*$	Reduction of $P680^+$ by water
B.	Reduction of $PQ(ox)$ by $P680^*$	Reduction of $PQ(ox)$ by $P680^*$
C.	Reduction of $PQ(ox)$ by $P680^*$	Reduction of $P680^+$ by water
D.	Reduction of $Fd(ox)$ by $P700^*$	Reduction of $Fd(ox)$ by $P700^*$

HP 3: I'll try to fix you

“Lights will guide you home; And ignite your bones; And I will try to fix you.” ~ Coldplay

Symbiotic nitrogen-fixing microorganisms often play a crucial role in the assimilation of nitrogen in nitrogen-poor environments. Jacob is investigating a nitrogen-fixing symbiont CCN that lives in seagrass root tissue. Jacob used FISH to visualise the primary locations of the CCN cells in the roots of the seagrass. The stitched epifluorescence images (black-and-white inverted) are seen below.

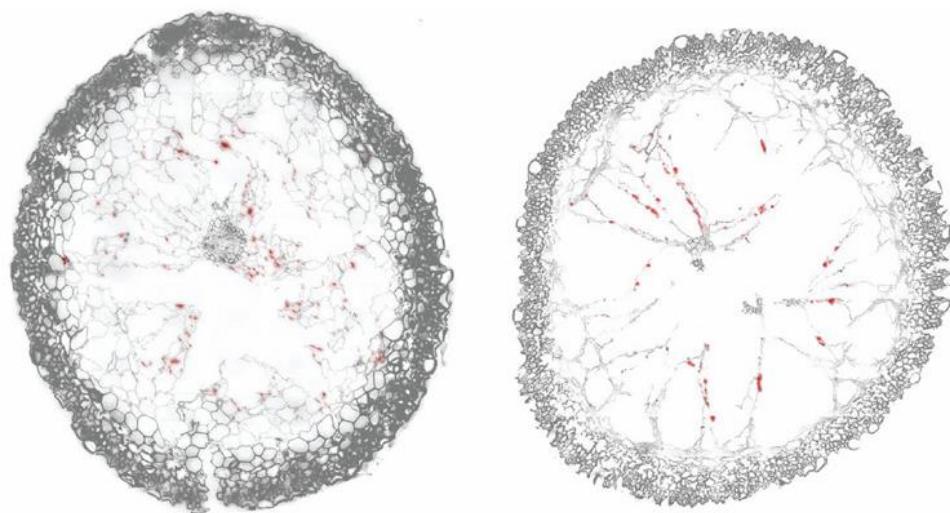


Figure 1

Jacob first measured the productivity of the seagrass meadows by measuring the oxygen fluxes (in green) of the seagrass over a 24-hour period. The results are shown below. The photosynthetically active radiation (PAR) is indicated in grey in the graph.

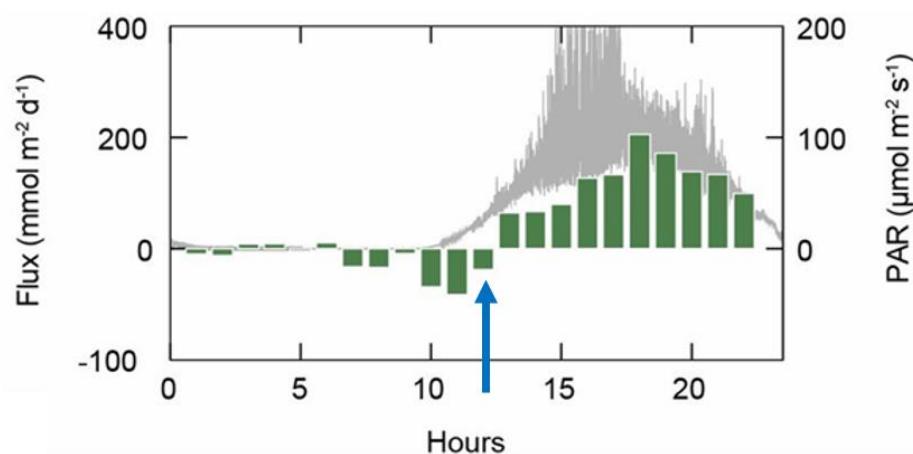


Figure 2

Next, Jacob conducted an $^{15}\text{N}_2$ -labelling experiment with the following set-up in Germany where the seagrass meadow and CNN in its roots are incubated together in different months. $^{15}\text{N}_2$ was added to the water and the $^{15}\text{N}_2$ concentration in the water was measured after 1 week for the set-ups in each month. The results are shown below.

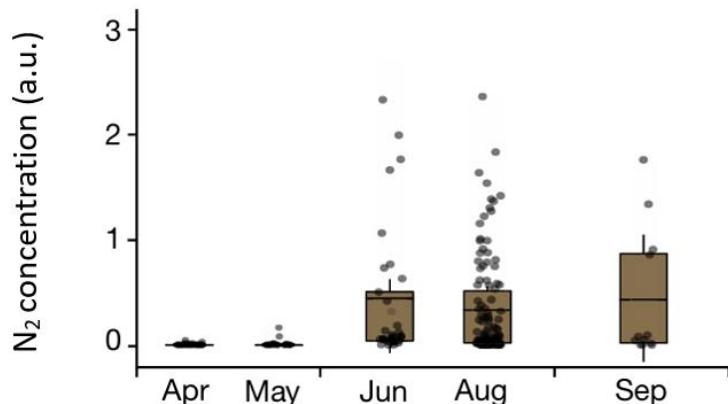


Figure 3

- I. The CCN cells are primarily located in the cortex of the root but not the rhizoplane.
- II. Hour 10 on Figure 2 is likely dawn.
- III. Since the flux is negative at the time indicated by the blue arrow on Figure 2, it is likely that no photosynthesis is occurring.
- IV. The net primary production of the seagrass meadows was approximately 800 to 900 mmol m⁻² of CO₂ fixed per day.
- V. Some of the $^{15}\text{N}_2$ that is transferred to the leaves in the set-up in Figure 3 will be stored as chlorophyll and sucrose in the leaves.

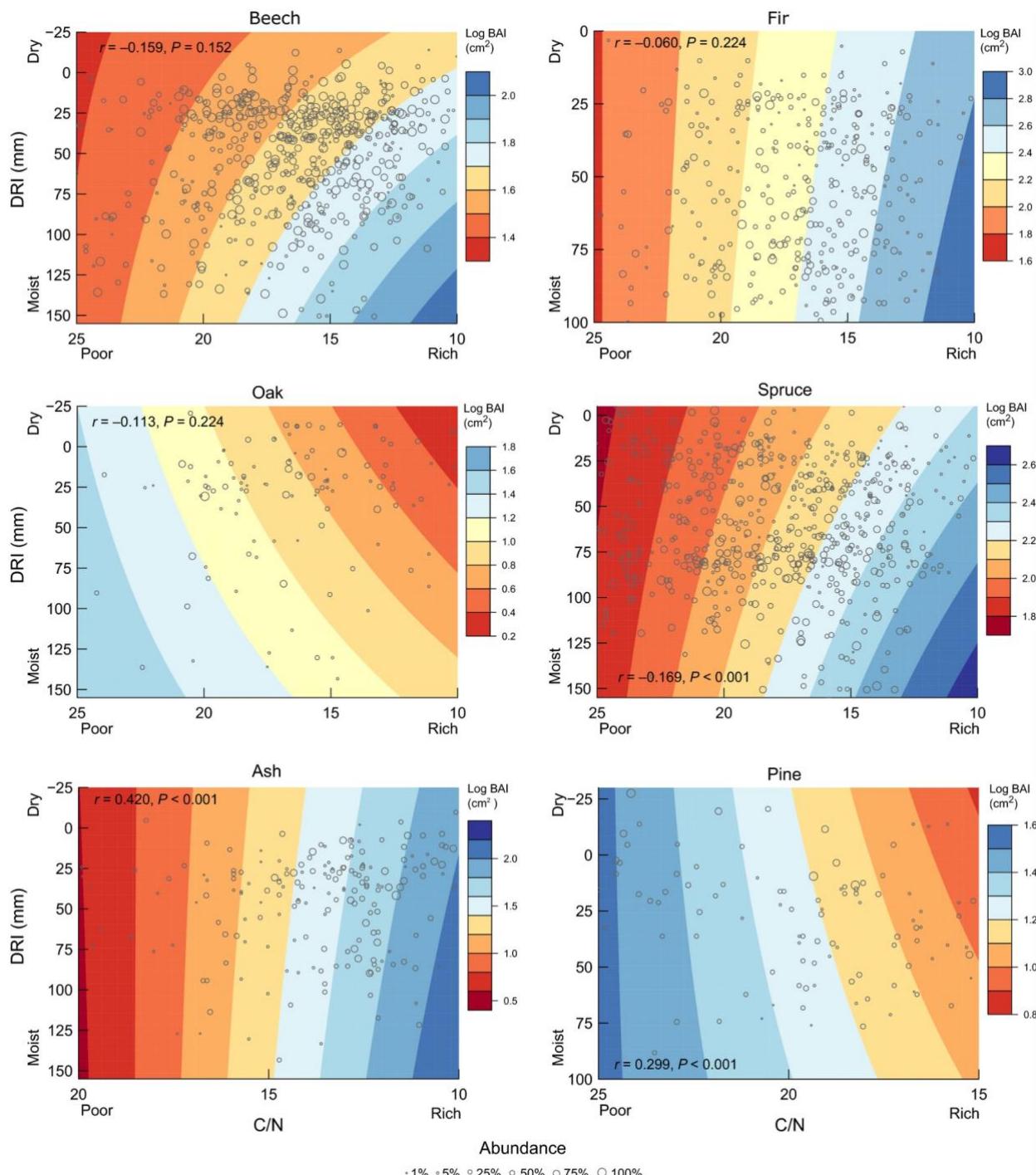
Which of the above statements are **false**?

- A. I, III, V only
- B. II, III, IV only
- C. II and V only
- D. III, IV, V only

HP 4: Swiss Food & Beverage Establishment

Recent research has shown that the nutrient composition of the soil affects the growth of trees. In particular, the carbon-nitrogen ratio (C/N) and drought index (DRI) of soil can impact the radial growth (known as the yearly basal area increment, or BAI) of different species of trees.

Several study sites in Switzerland and northern Italy were chosen to investigate six types of trees. At each site, the DRI and C/N of the soil, as well as the BAI of the trees were recorded. The figure below shows the graphs representing the data collected.



Some statements were made about the data from the figure above.

- I. Beech and oak can have similar radial growth rates in drought conditions and a high C/N ratio.
- II. Soil that contains ten times more carbon than nitrogen will be most suitable for oak and pine.
- III. Soil housing an equal abundance of ash and pine trees will likely have similar mass of carbon and nitrogen atoms.
- IV. Soil polluted with anhydrous sodium sulfate will stunt the growth of all six species.

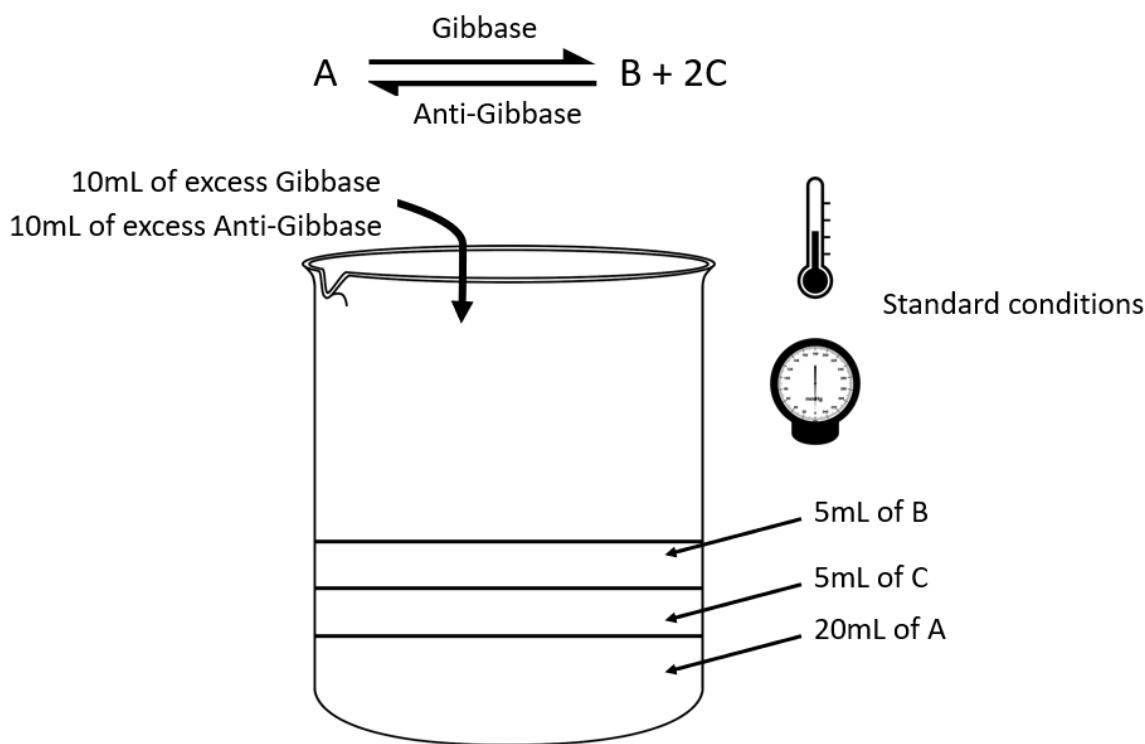
Which of the above statements are true?

- A. I only
- B. I, II, III only
- C. I and IV only
- D. II, III, IV only

HC 1: Gibby Gibby Gibby

Gibbase is an enzyme found in some members of the subphylum Cheliceratarata that catalyses the conversion of A to B and C. Gibbase aids in this process by providing an alternative reaction pathway with lower activation energy (E_a). However, gibbase does not alter the Gibbs free energy of the reaction. The standard change in Gibbs free energy of a reaction (ΔG°) indicates the thermodynamic favorability of a physical or chemical process. When $\Delta G^\circ < 0$, the process is thermodynamically favoured, while when $\Delta G^\circ > 0$, the process is not thermodynamically favoured. This can help to determine whether the reaction catalysed by gibbase is spontaneous or not.

You performed the experiment as shown below.

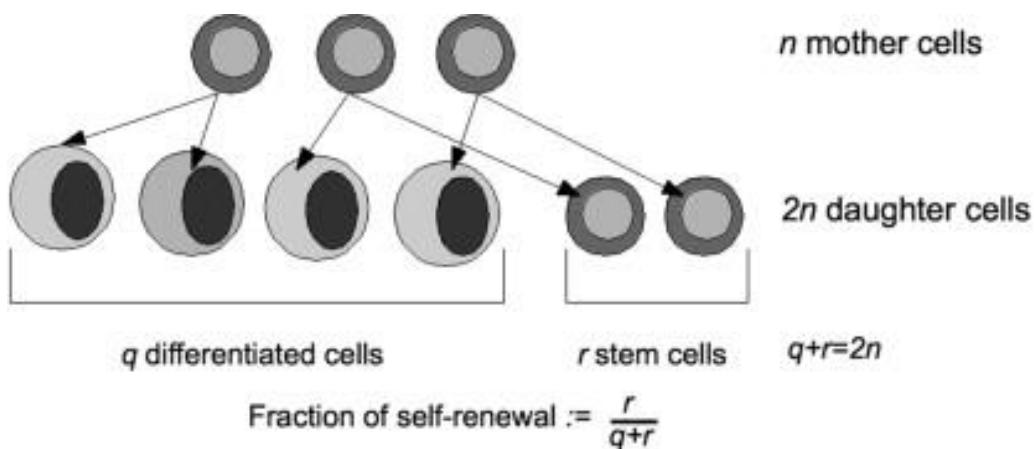


If the amount of A present in the final mixture is 0.0021 mol, while the amount of B is 0.029 mol and the amount of C is 0.00273 mol, what is the standard change in Gibbs free energy of the reaction (ΔG°) by gibbase (298K)?

- A. $-6.80 \text{ kJ mol}^{-1}$
- B. 6.80 kJ mol^{-1}
- C. $-7.90 \text{ kJ mol}^{-1}$
- D. 7.90 kJ mol^{-1}

HC 2: Steady lah!

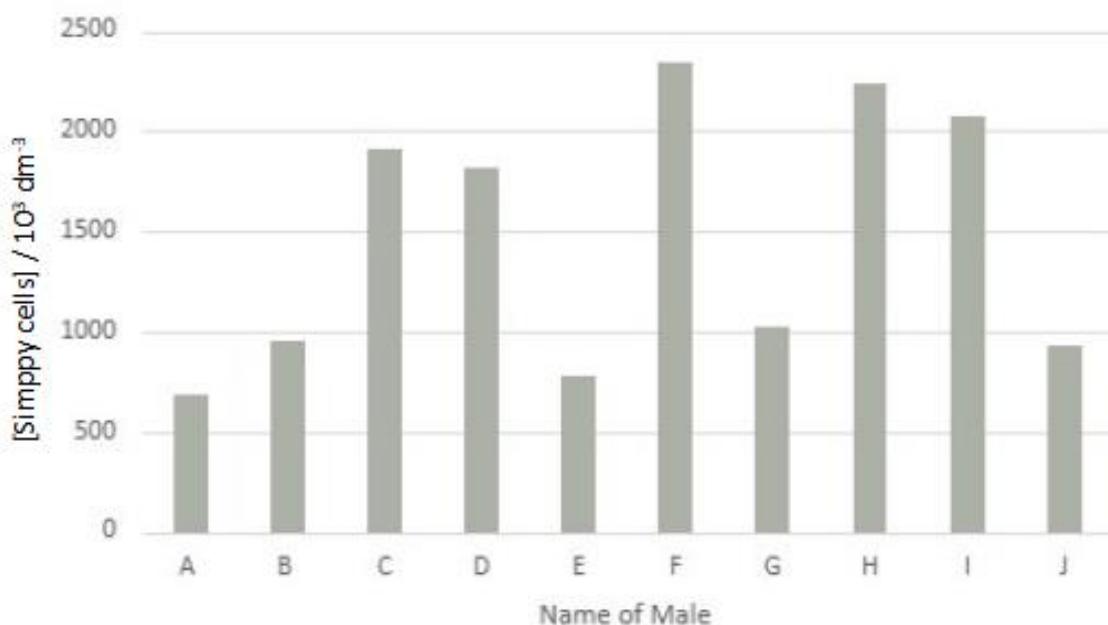
Cell differentiation refers to the process where stem cells convert into cells that are more specialised in their function. For example, haematopoietic stem cells in the bone marrow can differentiate into different types of blood cells such as erythrocytes and leukocytes. Stem cells are also capable of self-renewal. They can undergo mitosis to produce more copies of themselves, hence allowing for the maintenance of a constant level of stem cells. For each mitotic cycle, one cell can either produce two differentiated cells, one differentiated and one stem cell, or two stem cells. Hence, n mother cells can produce $2n$ daughter cells. The fraction of self-renewal is a quantitative measure of the proportion of progeny cells that are identical to the mother cells.



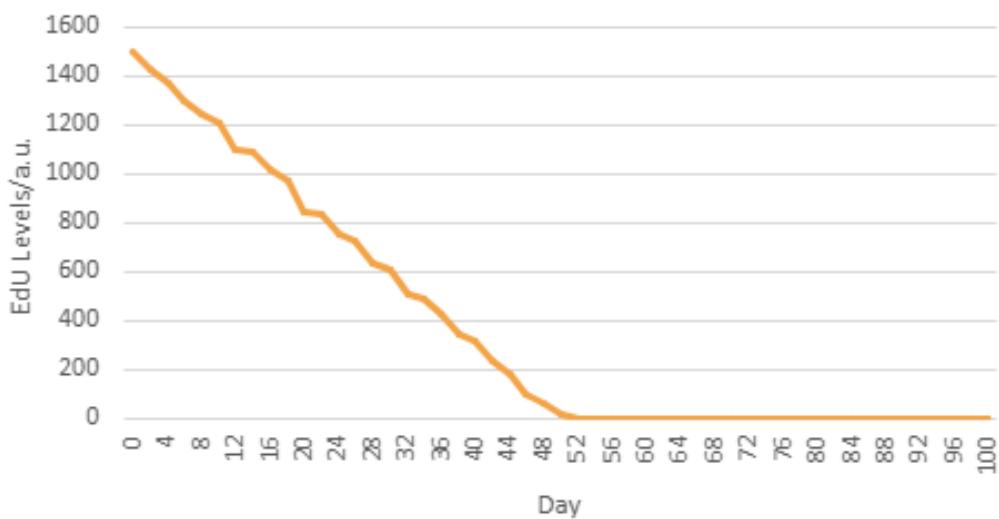
Jerome is investigating the differentiation rate of simponisa cells in giant male rats. Simponsia cells differentiate to form only simppy cells which regulate the levels of testosterone in the bloodstream. This cell cannot be produced by any progenitor cells other than simponisa cells. Thus, simponisa cells maintain a constant rate of differentiation to prevent any fluctuations in the levels of simppy cells. This also ensures that there are no fluctuations in the levels of simponisa cells. The fraction of self-renewal of simponisa cells is 0.5.

Jerome takes a blood sample from ten giant male rats to detect the levels of simppy cells in their bloodstream. These giant male rats have a total blood volume of five litres on average. Unfortunately, he realised later that while the rest of them are normal, five of them suffer from clingee, which cause antibodies to recognise the simppy cells as non-self.

The blood sample results are shown below.



Jerome also injected EdU (a thymidine analogue) into the bloodstream of several normal giant male rats on day 1 and then extracted their blood samples every two days for 100 days. He then precipitated the cells using anti-simppy cells antibodies and detected the levels of EdU using a fluorescent azide. The results are shown below.

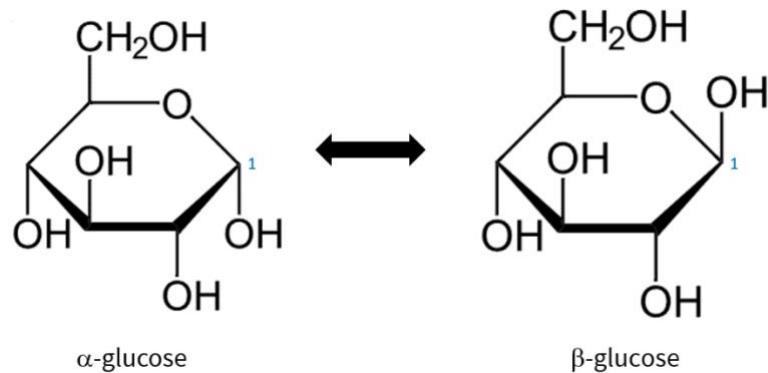


Estimate the average rate for simponisia cells to differentiate.

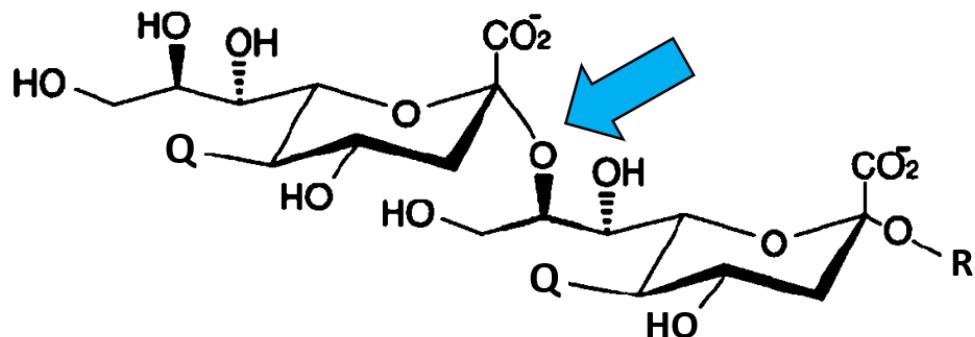
- A. 4×10^4 divisions/day
- B. 1×10^5 divisions/day
- C. 2×10^5 divisions/day
- D. 1×10^6 divisions/day

HC 3: Alpha and Beta

The diagram below shows the structure of alpha and beta glucose. What differentiates them is the specific stereochemistry of carbon 1.



The diagram below shows a molecule.

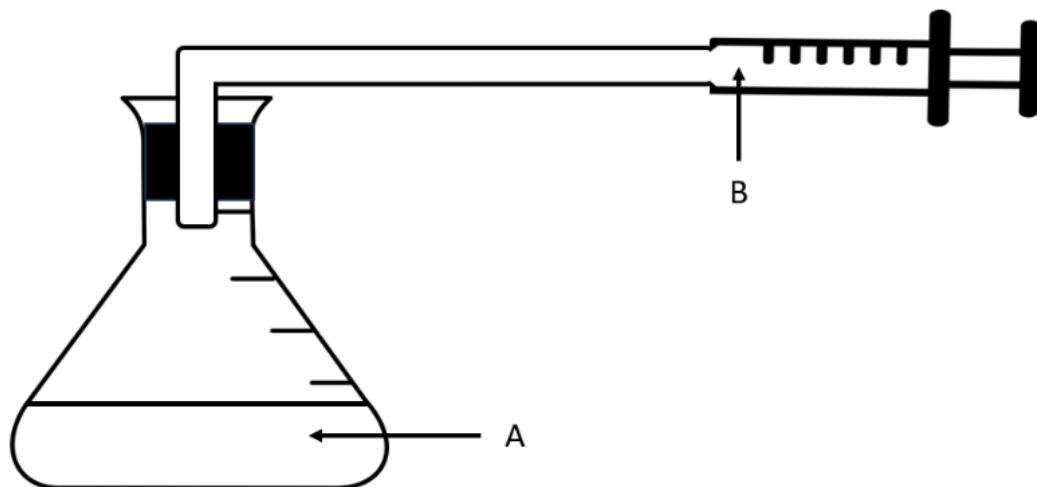


By analysing the stereochemistry of the molecule above, what glycosidic bond is indicated by the blue arrow?

- A. $\beta(1,7)$
- B. $\alpha(2,2)$
- C. $\beta(2,7)$
- D. $\alpha(2,8)$

HC 4: Bubbles

To investigate the effects of poison X on respiration, Rachel placed a glucose solution containing ^{14}C instead of ^{12}C with yeast cells in a conical flask. She then repeated the experiment by adding poison X in a similar conical flask. The radioactivity of the glucose solution initially is 6 Bq. Assume oxygen is present in excess in the conical flask.

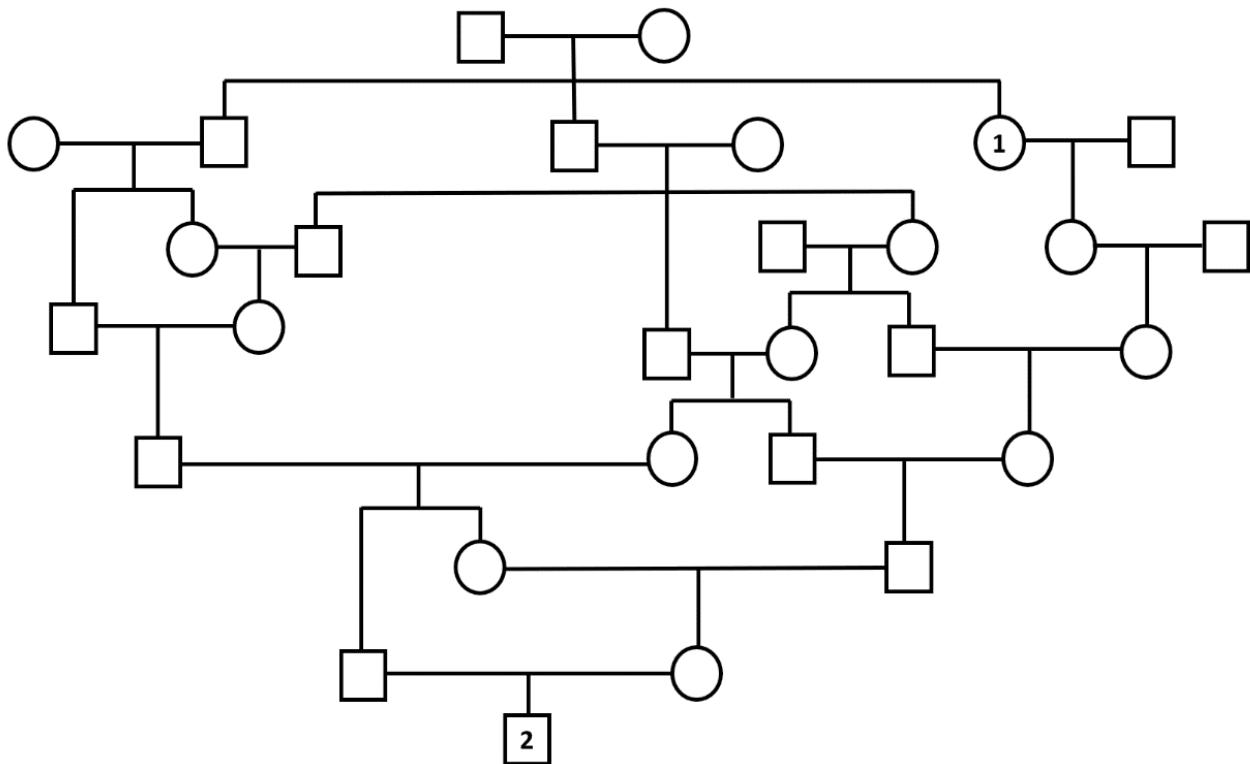


The table below shows the possible radioactivity levels of A and B after all the glucose has been metabolised. Which of the following results would be observed if poison X inhibits coenzyme Q in the electron transport chain?

Radioactivity (Bq)				
	Without X		With X	
	A	B	A	B
A.	0	6	4	2
B.	0	6	6	0
C.	4	2	6	0
D.	4	2	4	2

HG 1: Haus Habsburg

Charles II of Spain ruled as the King of Spain from 1665 to 1700 and was the last monarch from the House of Habsburg which had ruled Spain since 1516. The diagram below shows the family tree of Charles II. Individual 1 is Isabella of Austria (1501-1526), while Individual 2 is Charles II of Spain (1661-1700).



What is the coefficient of relatedness between Individuals 1 and 2?

- A. 0.0156
- B. 0.0178
- C. 0.211
- D. 0.227

HG 2: Caryotyping

Karyotyping is a test used to identify chromosome abnormalities. It is performed by extracting a sample of blood and performing karyotype analysis on it. Differences in the shape and staining pattern of the chromosome can indicate a possible aberration.

The figures below show the karyotypes of four children (Individuals A-D).

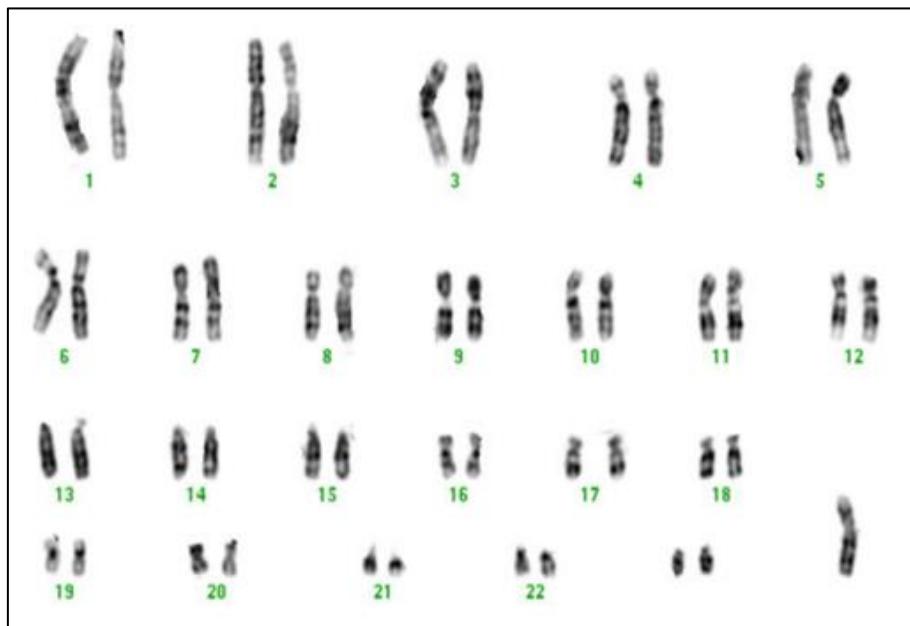


Figure 1: Karyotype of Individual A

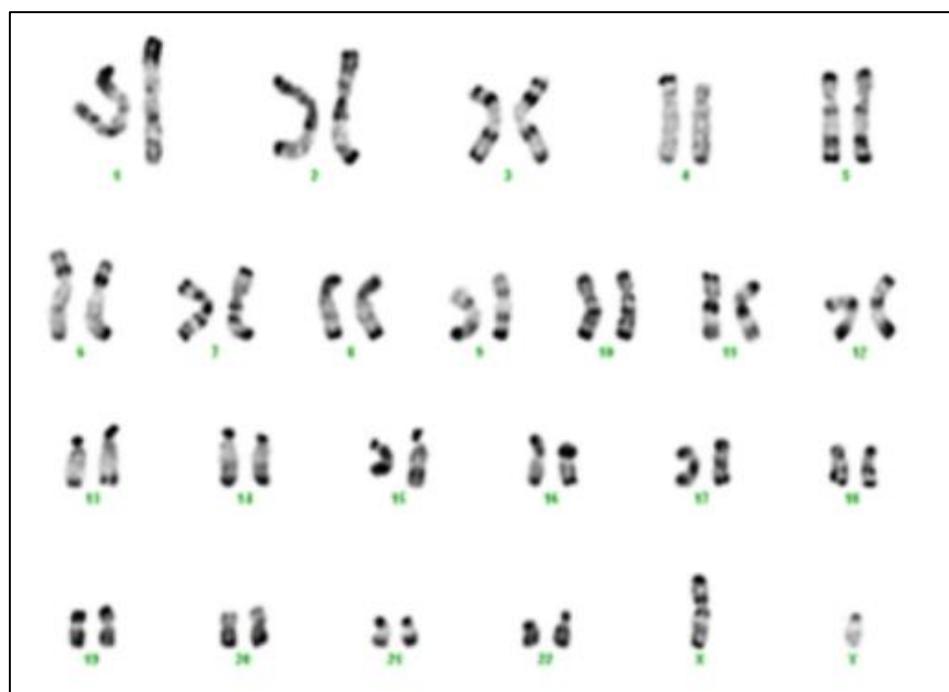


Figure 2: Karyotype of Individual B

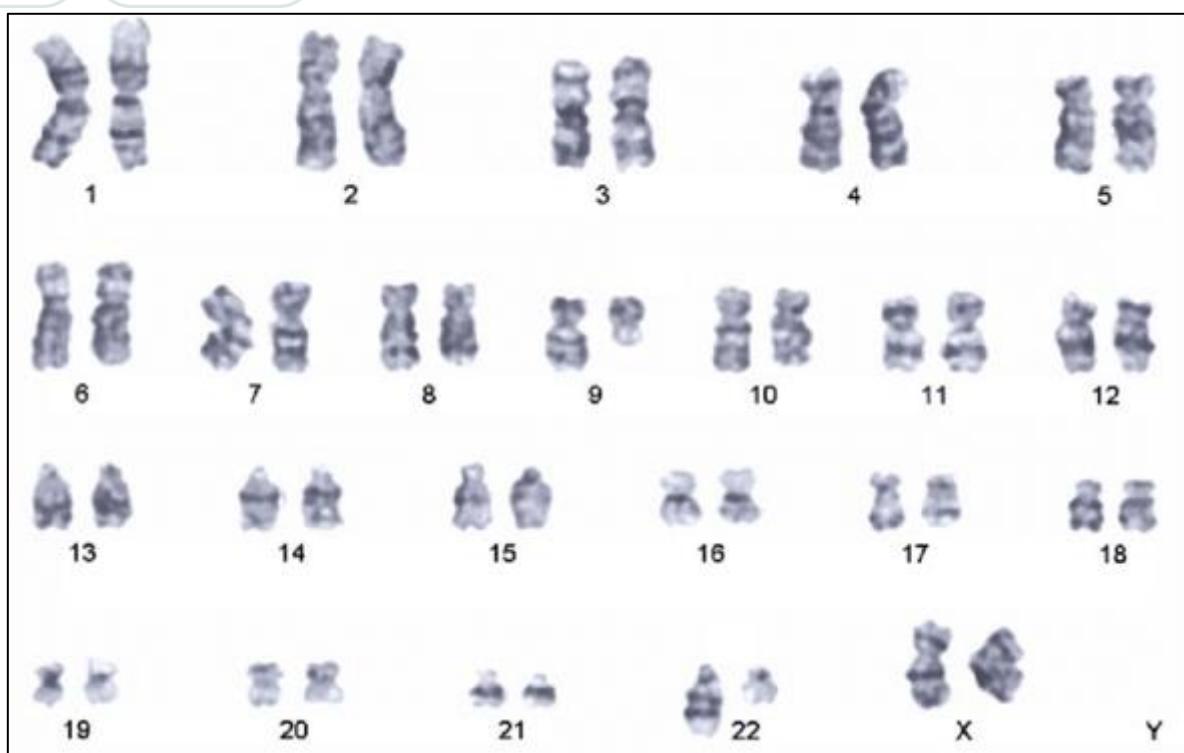


Figure 3: Karyotype of Individual C

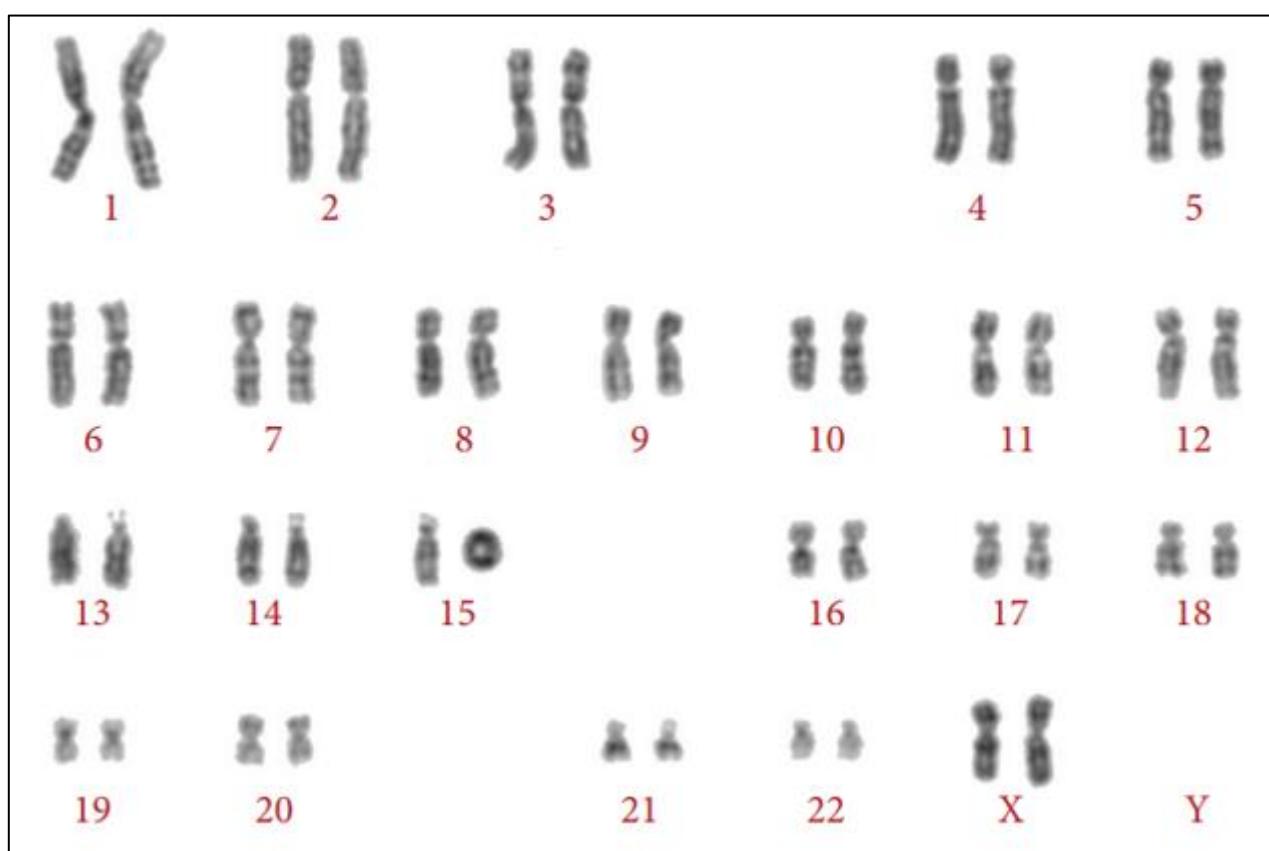


Figure 4: Karyotype of Individual D

A geneticist made several conclusions regarding the four children (A-D) from their karyotypes.

- I. After reaching reproductive age, Individual A likely can still ejaculate semen but there will be no sperm in the semen.
- II. The karyotype of Individual A is likely due to non-disjunction during meiosis I in the germ cell.
- III. Individual B has a duplication in one of the chromosomes.
- IV. The rate of cell division is likely increased in Individual C.
- V. Individual D has a deletion in both the p and q arms of a chromosome.

From the karyotypes in Figures 1-4, which of the above conclusions are true?

- A. I, II, III only
- B. I, III, V only
- C. I, IV, V only
- D. II, IV, V only

HG 3: Reversi

Mutations are rare but they do occur in nature at an extremely low rate. This is the forward rate.

Mutations in organisms can also occur in the opposite direction, with the deleterious allele being mutated back to the normal allele. The reverse rate is even lower and is often negligible.

The gene P/p codes for the colour of hair on the tails in squirrels. In a population of 1 million squirrels, there are 296 478 heterozygotes, with more dominant homozygotes than recessive homozygotes. A dominant allele P mutates to the recessive allele p in a population of squirrels at a rate of 3×10^{-8} . However, the reverse rate is effectively negligible. You are given that the dominant allele P is more common. Assuming the population of squirrels is at equilibrium and that the relative fitness of PP and Pp is 1, calculate the selection coefficient of pp .

- A. 8.22×10^{-7}
- B. 9.16×10^{-7}
- C. 1.09×10^{-6}
- D. 1.64×10^{-6}

HG 4: Same same but different

The phenotypic variance (V_P) of a particular trait for a population is the result of genetic factors (V_G) and environmental factors (V_E). V_P is the sum of V_G and V_E as shown in the equation: $V_P = V_G + V_E$

Petaurista leucogenys (Figure 1), also known as the Japanese giant flying squirrel, is a species of flying squirrel that has a tail length of 30-40 cm.



Figure 1: *Petaurista leucogenys*

A geneticist wants to investigate the extent that genetic factors (V_G) contribute to the phenotypic variance of tail length in a small population of *Petaurista leucogenys*, population **S**.

Before beginning his study, he develops another population of *Petaurista leucogenys* in his laboratory. Population **T** was started by a randomly selected true-breeding male from population **S**, where stem cells were taken and developed into sperm cells and egg cells before fertilisation *in vitro*. Future generations of population **T** were conceived typically between members of population **T** only.

Tail lengths of a random sample of 80 adult individuals from each of the two populations were recorded, and their phenotypic variances were calculated.

	Mean tail length / cm	Variance / cm
Population S	32.8	8.4
Population T	24.6	2.1

★★ Hard

DNA Genetics

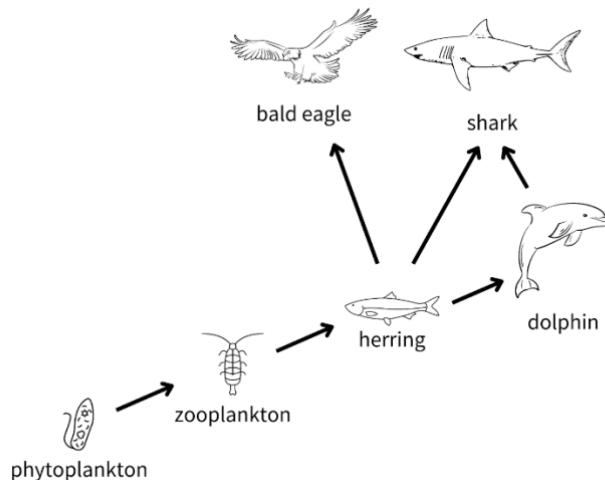


Find V_G of population S for tail length.

- A. 4.0
- B. 6.3
- C. 10.5
- D. Insufficient data to determine

HE 1: Lead the way

A partial food web of a community is shown below.



Lead is a heavy metal that competes for calcium within an organism. Due to substantive long-term pollution, traces of lead were found in the local seawater. Researchers caught samples of herring, dolphin, shark and bald eagle to determine the average amount of lead each contained.

	Lead / ppm
Herring	0.113
Dolphin	0.038
Shark	0.003
Bald eagle	0.049

Which of the following statements is most likely true given the information above?

- A bloom of phytoplankton will increase the average lead concentration of species up the food chain.
- Dolphins have a lower tissue concentration of lead than bald eagles as bioturbation of lead occurs in the seawater.
- Species of higher trophic levels exhibit increasingly efficient excretion of metals.
- Biomagnification is not observed in this scenario as the amount of lead in lower trophic level species greatly exceeds the number of calcium-binding sites.

HE 2: Impostor

Brood parasites are birds that lay eggs in other species' nests for the allospecific host to care for their young. Parasitic eggs may look extremely similar to host eggs.

One example is the relationship between the parasitic common cuckoo and the host Oriental magpie-robin. The figure below shows a female magpie-robin unknowingly feeding a cuckoo chick.

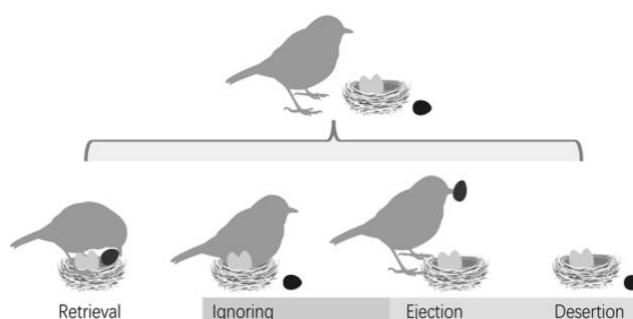


A study was done on a population of Oriental magpie-robins exploited by brood parasites, and a population of the closely related white-rumped shama not exploited by brood parasites.

Model eggs, as shown in the figure below, were placed outside of shama nests (left) and magpie-robin nests (right). Data was recorded on whether the host bird **accepts**, **ignores**, or **rejects** the model egg.



Egg acceptance is qualified as the behaviour of egg retrieval, a fixed action pattern in both the birds to roll the egg back into their nest using their beak as support. **Egg rejection** is qualified as the behaviour of egg ejection or desertion. **Egg ignoring** is qualified as the behaviour of interacting with the model egg without explicit acceptance or rejection.



The results of the study are summarised in the table below.

	Total number of model eggs	Number of model eggs accepted	Number of model eggs ignored	Number of model eggs rejected
Magpie-robins	142	0	71	71
Shamas	137	18	102	17

A few statements were made regarding the results.

- I. Some cases of egg rejection could have started after a partially-complete action of egg retrieval.
- II. Shamas have weaker egg recognition abilities than magpie-robins.
- III. Magpie-robins are more uncertain than shamas in deciding between accepting and rejecting the model eggs.
- IV. Egg rejection is a learned behaviour.
- V. Egg retrieval is a learned behaviour.

Which of the above statements are true?

- A. I and III only
- B. II only
- C. II, IV, V only
- D. III, IV, V only

HE 3: The Sun's a Deadly Lazer

You are visiting a research centre in Antarctica and you find several graphs pinned on a billboard.

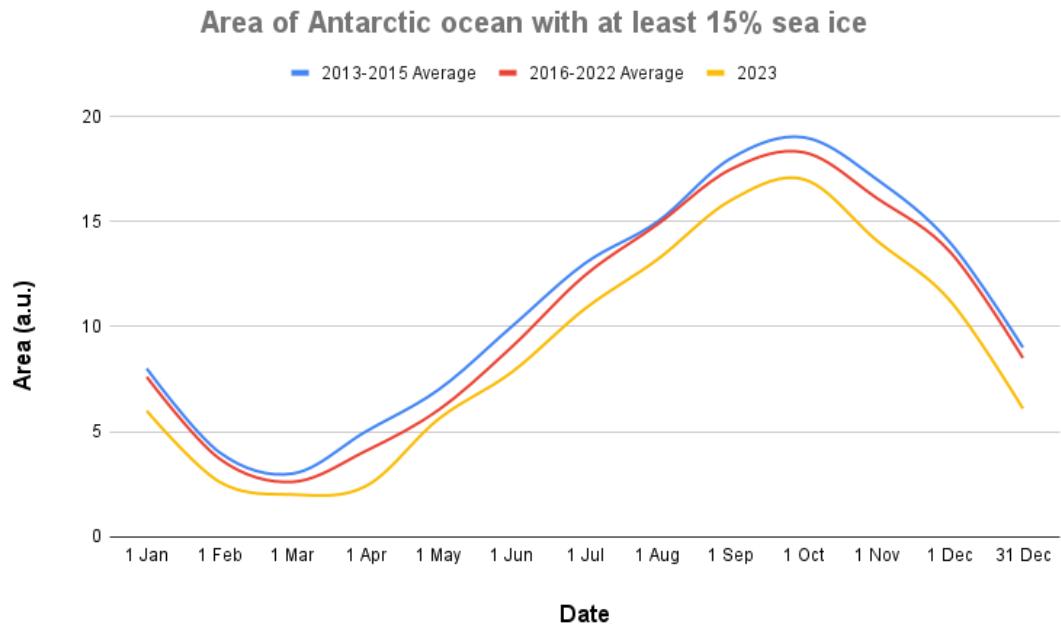


Figure 1: Sea ice extent in the Antarctic ocean

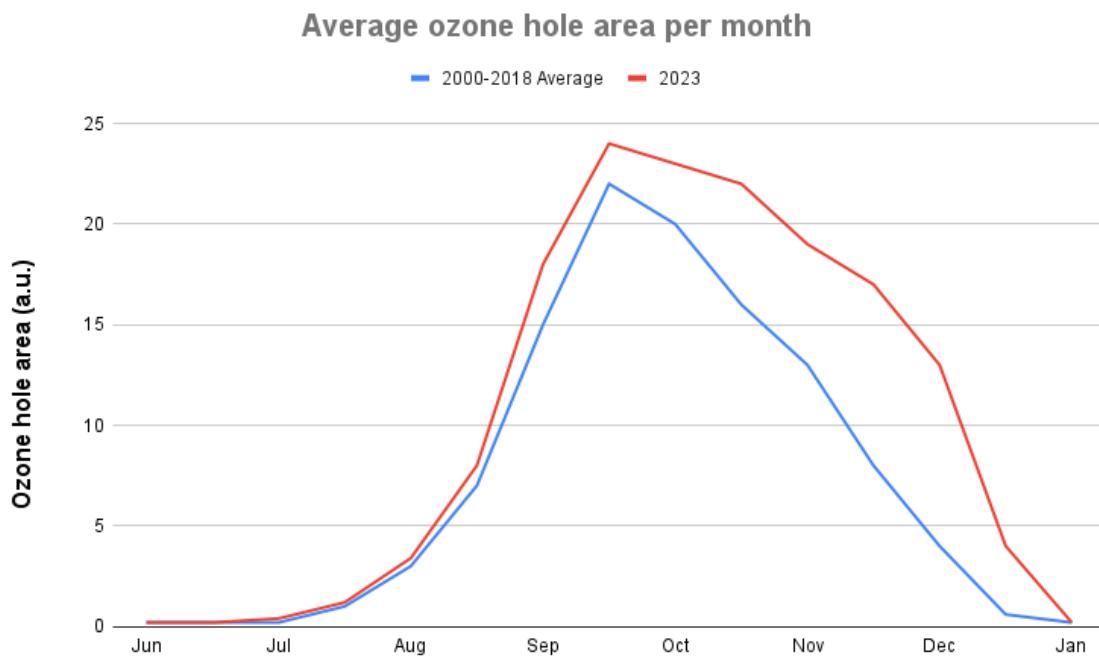


Figure 2: Average ozone hole area in each month

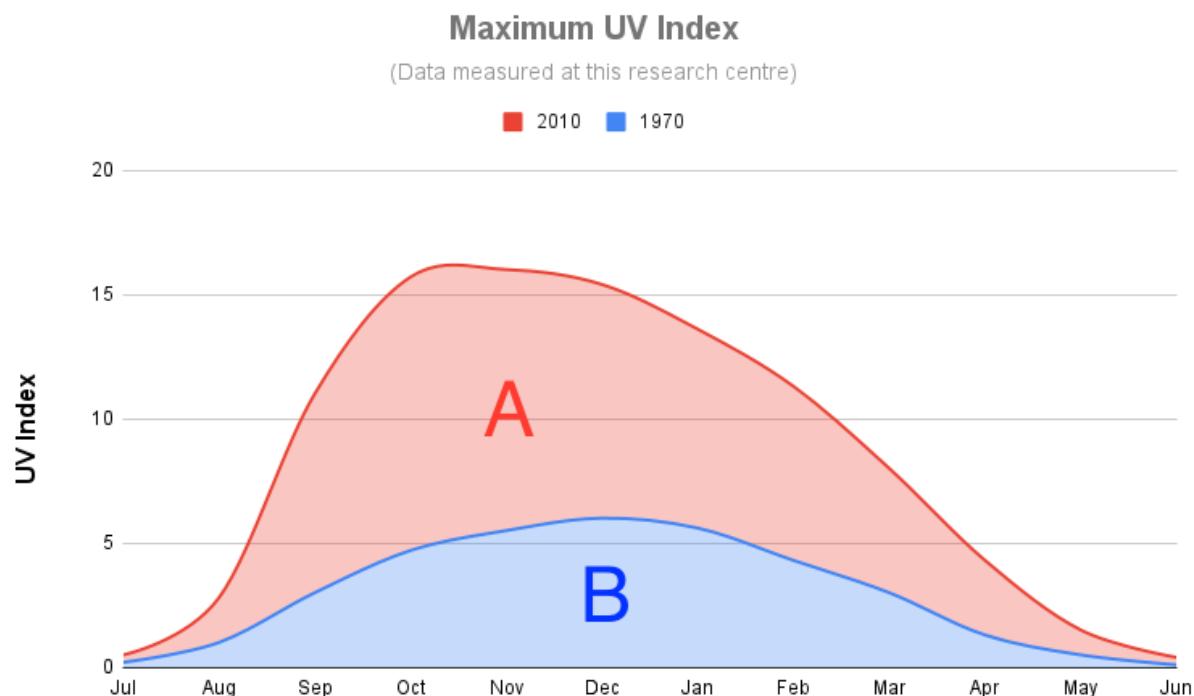


Figure 3: Maximum UV index measured by this research centre situated in Antarctica. The area between the two graphs is labelled A (red), while the area below the 1970 graph is labelled B (blue).

Several statements were made regarding the graphs.

- I. Figure 1 suggests an increase in sea level between 2013 and 2023.
- II. The closing of the ozone hole is a longer process in 2023 compared to 2013.
- III. Area A in Figure 3 is likely the consequence of anthropomorphic emissions of carbon dioxide.
- IV. Assuming the UV index is similar between September and December, marine creatures are more vulnerable to the effects of UV radiation in September than December.

Which of the above statements are true?

- A. II only
- B. I and II only
- C. I, III, IV only
- D. I, II, III, IV

HE 4: La Signora's Lackeys

Two populations of moth, the childe moth and balladeer moth, have lived in similar habitats in a dense, isolated forest for centuries. Eight individuals of each species were captured from the monotone bark of the same tree and photographically scanned by a team of ecologists, as shown in the figures below.



Above: Eight **childe moths** from the forest.



Above: Eight **balladeer moths** from the forest.

The table below contains five statements (I-V).



Above: A kabukimono moth.

- I. The kabukimono moth exhibits Mullerian mimicry with the balladeer moth.
- II. The variability in the colouration of balladeer moths is an example of adaptive radiation.



Above: An unknown caterpillar.

- III. The caterpillar shown in the figure above is more likely a childe moth than a balladeer moth.
- IV. If both moths do not exhibit phenotypic plasticity, the gene pool for wing colouration of the childe moth is larger than that of the balladeer moth.
- V. The balladeer moth is more likely to have a regular temporal activity pattern than the childe moth.

★★ Hard

Ecology



Which of the above statements are likely true?

- A. I and II only
- B. II, III, IV only
- C. II, IV, V only
- D. III and V only