Singapore Biology League 2024

Adrenaline Rush Problems and Answers

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AR Grids

Easy

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

Medium

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

Hard

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

Easy Animals

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.

Easy Animals

Answer: **D**

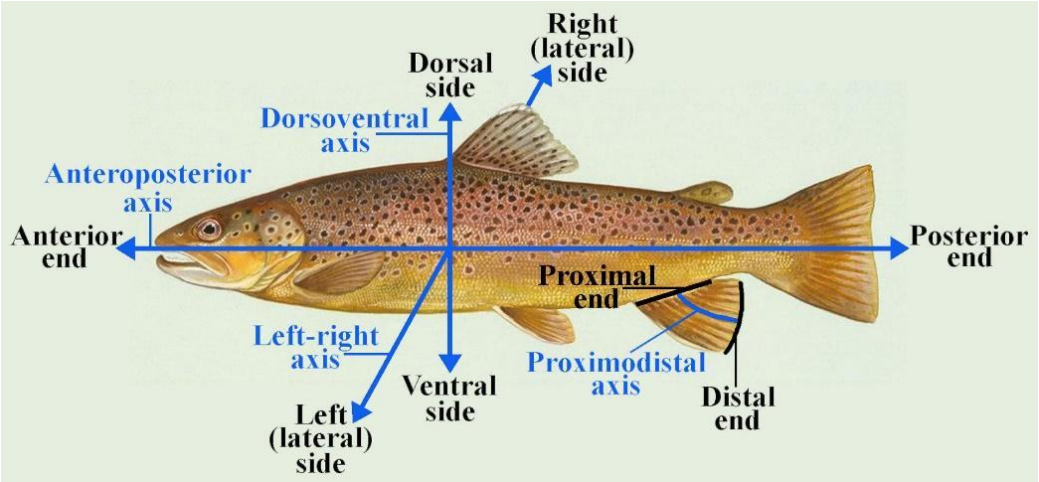
Explanation: The experiment proved that the material of the cowpox sore, after inoculation, helps prevent James Phipps from developing smallpox. This was the first successful vaccination in the world.

A. No information regarding whether James Phipps developed cowpox is given. Moreover, James Phipps not developing cowpox may be due to other reasons such as successful vaccination by the cowpox material.
B. The material could contain the proteins released by cowpox but not necessarily the virions.
C. There is no evidence of this.
D. The transferring of the cowpox material to James Phipps kept him immune from smallpox. Smallpox is extremely contagious and thus the fact that he did not develop it after exposure suggests that he was immune.

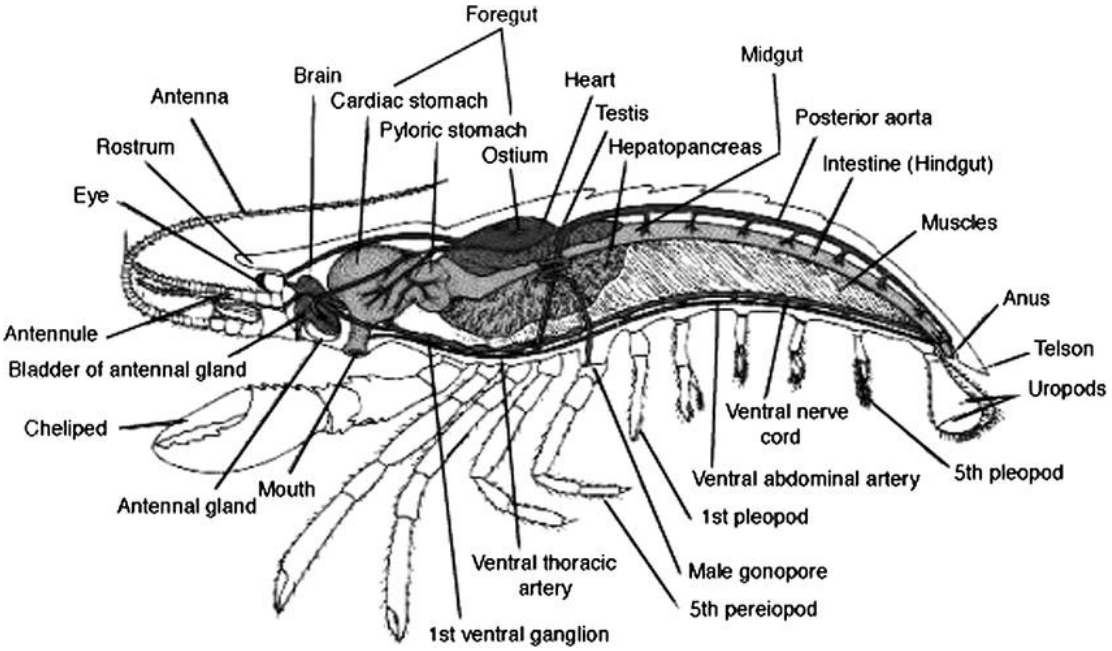
Easy Animals

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?

A. The foregut is posterior to the testis.
B. The cheliped is ventral to the pereiopods.
C. The uropods are paired and lie posterior to the mouth.
D. The telson is distal to the uropods.

Easy Animals

Answer: **C**

Explanation:

A. The foregut is anterior to the testis.
B. The cheliped is anterior to the pereiopods.
C. The uropods are paired as there are two of them, and they lie posterior to the mouth.
D. The telson is dorsal to the uropods.

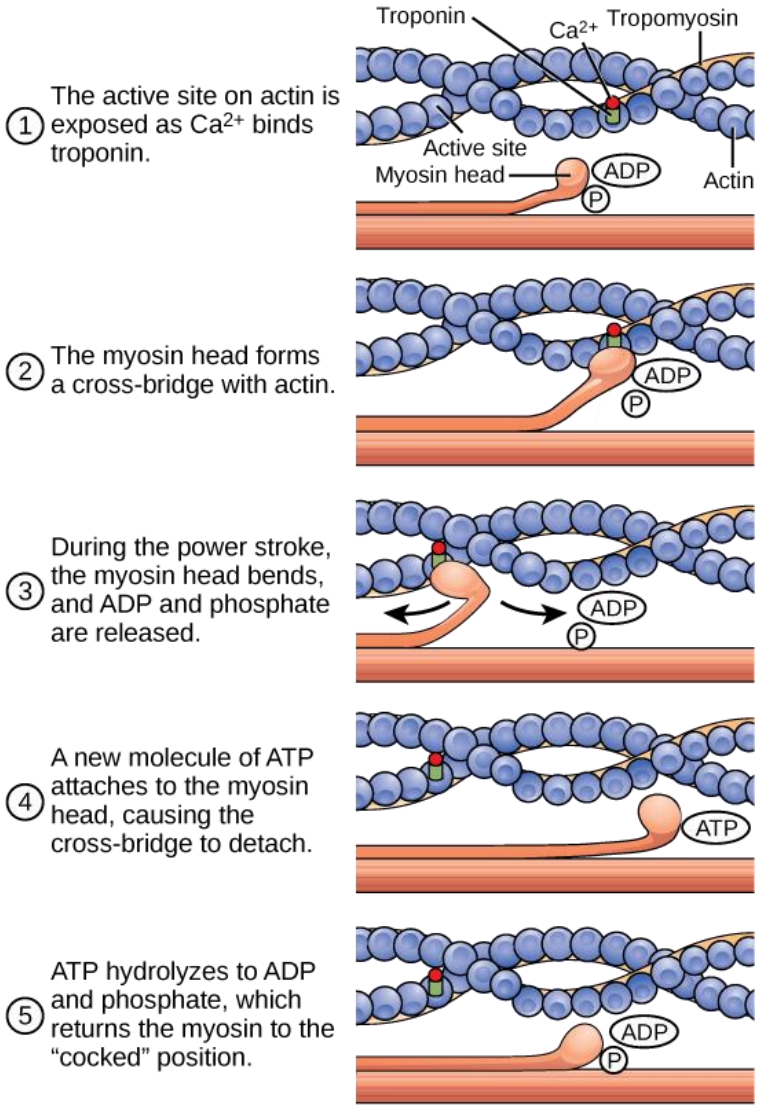
Credits:

Prawn: Goy, J. W. (2010). Infraorder Stenopodidea Claus, 1872. *Treatise on Zoology - Anatomy, Taxonomy, Biology. The Crustacea*, *9A*, 215–265. https://doi.org/10.1163/9789004187801_009

Easy Animals

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

Easy Animals

Answer: **B**

Explanation: Rigor mortis implies stiffening of muscles due to the myosin head remaining attached to the actin filaments, as there is no ATP to cause the cross-bridge to detach. Active muscle contraction of the skeletal muscles can cause locked jaw, arms being held upwards towards the sky and difficulty in folding the limbs. In contrast, urination and defecation is caused by relaxation of the external sphincter muscle of the bladder and anus respectively.

Credits:

Libretexts. (2023, October 31). *38.17: Muscle contraction and locomotion - ATP and muscle contraction*. Biology LibreTexts. https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/General_Biology_%28Boundless%29/38%3A_The_Musculoskeletal_System/38.17%3A_Muscle_Contraction_and_Locomotion_-_ATP_and_Muscle_Contraction

Easy Animals

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

Easy Animals

Answer: **D**

Explanation:

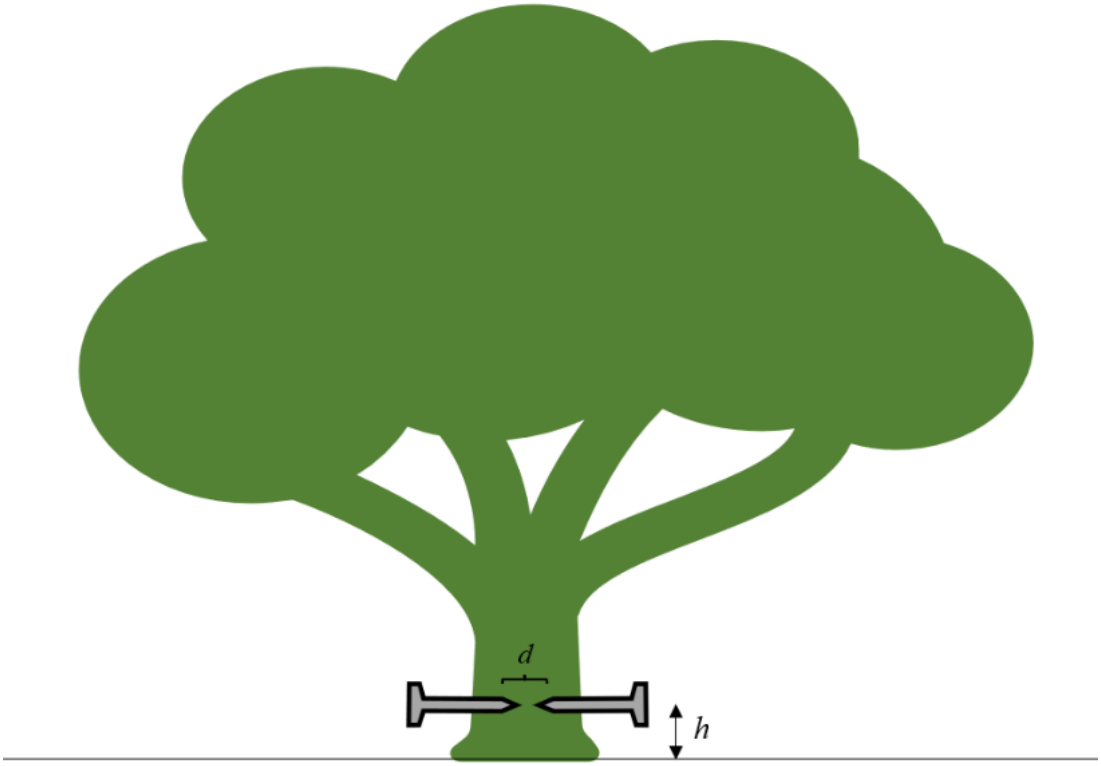
A. Kwashiorkor is the lack of proteins and xeropthalmia is an eye disease causes by Vitamin A deficiency.
B. Neural tube defects occur in the foetus when there is a deficiency in vitamin B9 (folate) in the mother. As Bernadette is already a teen, she will not develop neural tube defects. Scurvy is a lack of Vitamin C.
C. Anaemia can occur due to a lack of Vitamin B9 (folate) and B12 (cobalamin). Beriberi occurs due to a lack of Vitamin B1 (thiamine).
D. Kwashiorkor is the lack of proteins and rickets is the lack of Vitamin D.

Easy Plants

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

Easy Plants

Answer: **A**

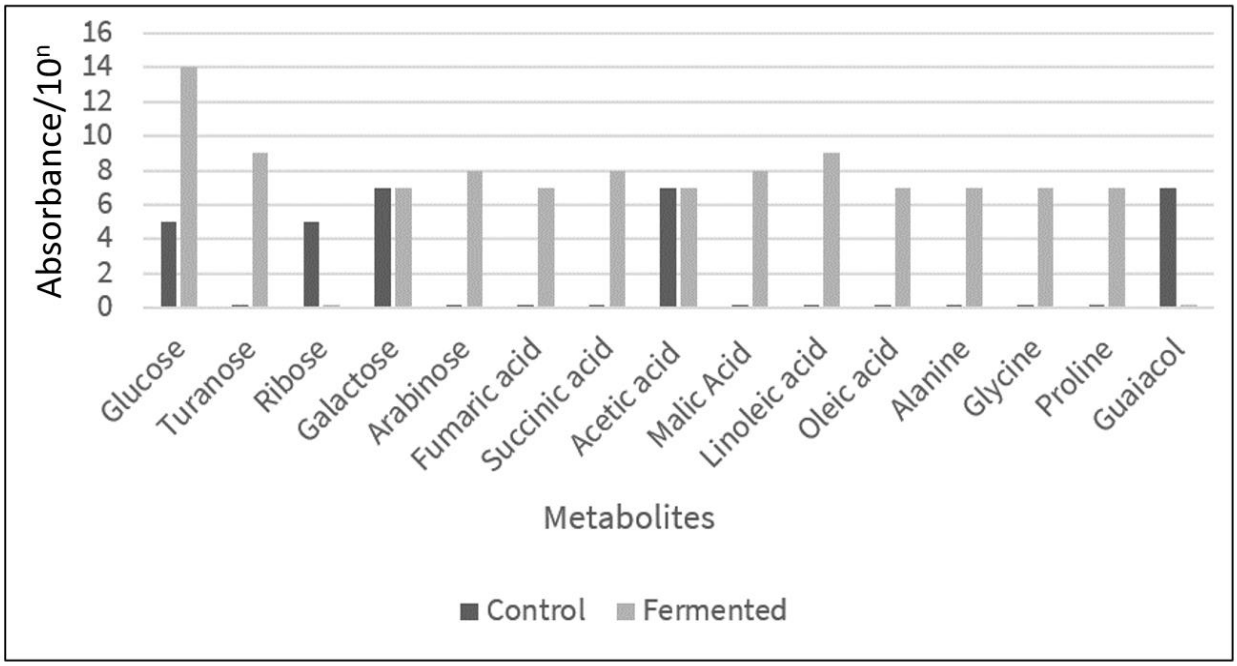
Explanation: As stated in the preamble, primary growth occurs at the apical meristem at the top of the tree. Therefore, the tree grows in height from the top of the tree, so the nail will remain at the same height above the ground. In secondary growth, however, the phloem cells are added outwards yearly by the lateral meristems to thicken the stem, so the nails will move outwards and the distance between them will increase.

Easy Plants

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.



Easy Plants

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

Easy Plants

Answer: **C**

Explanation:

A. The absorbance level increased from 10^5 to 10^{14}, thus it increased by 10^9 times.
B. Amino acid levels rose implying that proteins were digested to amino acids due to the production of proteases by the fungus.
C. Similarly, fatty acids increased which imply that the lipids were digested into fatty acids and glycerols by lipase.
D. There is not much information to deduce this but there is information that contradicts this. There is a rise in intermediates of the Krebs cycle like fumaric acid and succinic acid implying that the Krebs cycle occurred. Thus, aerobic respiration likely occurred.
E. The rise of fatty acids after fermentation suggests that pH would likely fall as it becomes more acidic.

Easy Plants

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

Easy Plants

Answer: **B**

Explanation: While participants may not be familiar with the adaptations, participants should be able to analyse each adaptation and make an educated choice on which option is the least likely to be an adaptation. Mangroves are halophytes and live in highly salty and anoxic environments, and thus need adaptations to reduce salt levels and aerate the plant.

A. Salt-secreting glands on the leaves allow the mangrove plant to secrete large amounts of the toxic ions that accumulate in the leaves.
B. The pneumatophores help the mangrove in gaseous exchange. It would not make sense for it to capture non-salty rainwater as the roots have such a low surface area to volume ratio and will face much difficulty in capturing and absorbing the water. Moreover, they do not lack water as they are flooded with it; what mangroves need is the ability to expel the salts out without water loss.
C. Mangrove propagules germinate while still attached to the parent plant (vivipary) so that the young plant is able to develop the adaptations without being exposed to the anoxic and salty environments first. This prevents the propagules from dying quickly due to the poor environments and allows them to develop until they are able to handle growing independently.
D. The lenticels are pores that allow for gaseous exchange. They also close up during high tides to prevent the mangroves from drowning.

Credits:

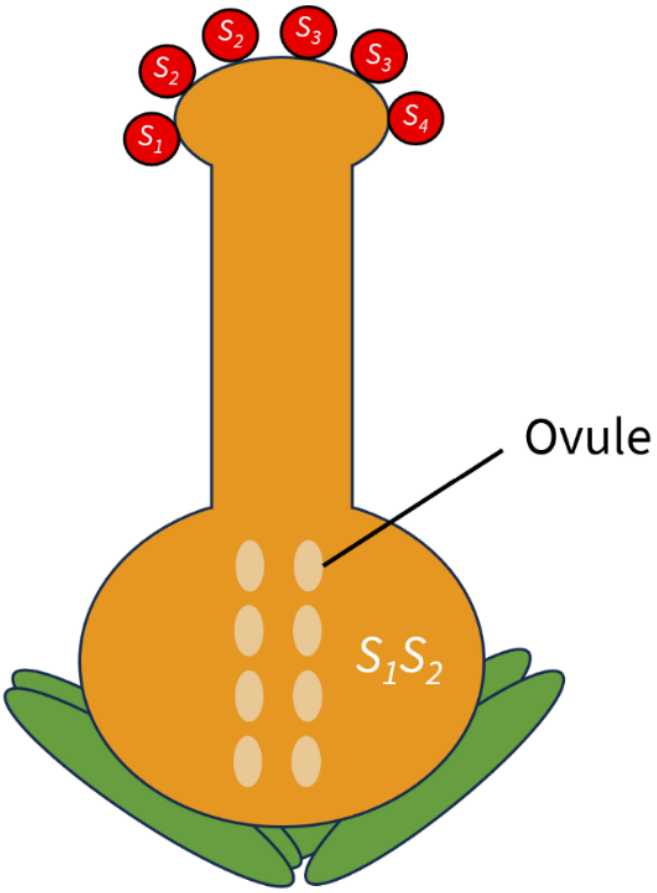
Figure and content reference: Siew, F. (2021, November). *Trees of the Mangroves*. NParks Buzz. https://www.nparks.gov.sg/nparksbuzz/nov-issue-2021/conservation/trees-of-the-mangroves

Easy Plants

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, …). 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

Easy Cell Biology

Answer: **C**

Explanation: Since the genotype of the female plant is S_1S_2, pollen grains with genotype S_1 or S_2 cannot fertilise the ovules. Hence, only the pollen grains with genotype S_3 and S_4 in this cross can ferilise the ovule. Hence, four different genotypes of zygotes can be formed: S_1S_3, S_1S_4, S_2S_3, and S_2S_4.

Easy Cell Biology

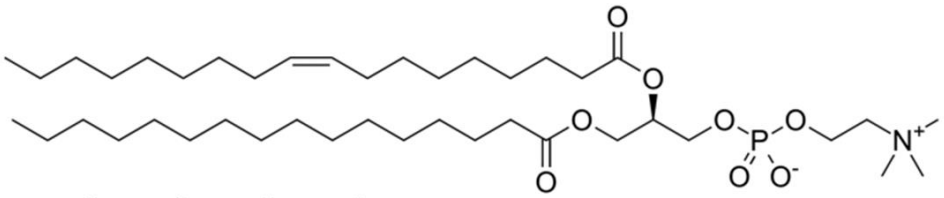
EC 1: Membranous Membranes

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.

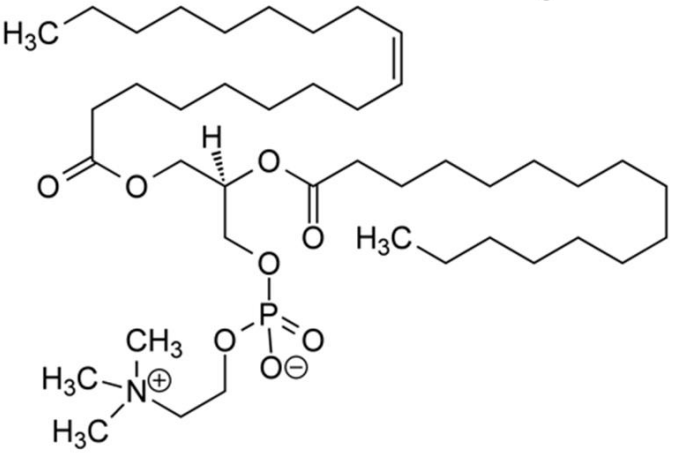
Imagine you created a new species of organisms with cells that contain plasma membranes too. However, the plasma membrane is only made of a single layer of phospholipids.

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

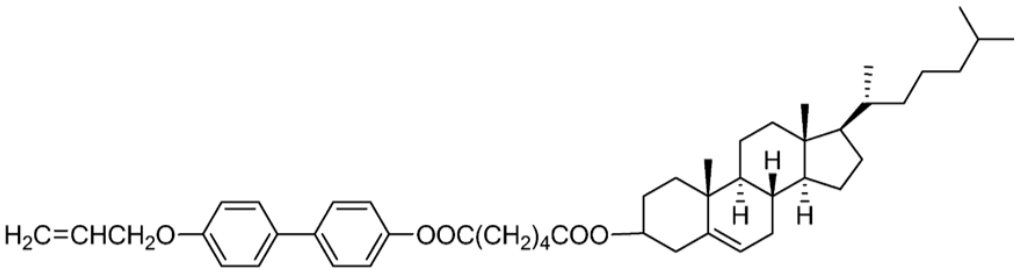
A:



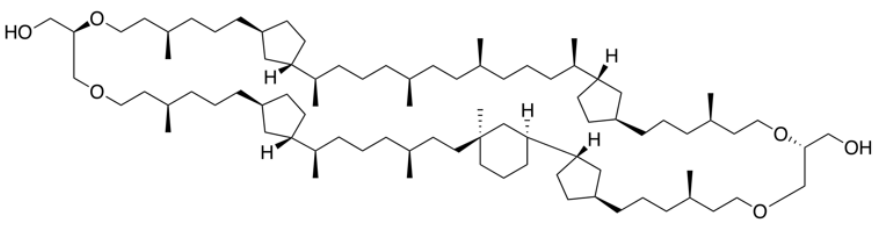
B:



C:



D:



Easy Cell Biology

Answer: **D**

Explanation: Participants may have noticed that this is similar to the Domain Archaea which have monolayered plasma membranes. You would need to select a molecule that is hydrophilic on both ends to interact with the aqueous extracellular and intracellular environments, and have a hydrophobic middle region which forms the hydrophobic core of the plasma membrane. This is similar to the Eukarya plasma membrane with two rows phospholipids facing away from each other.

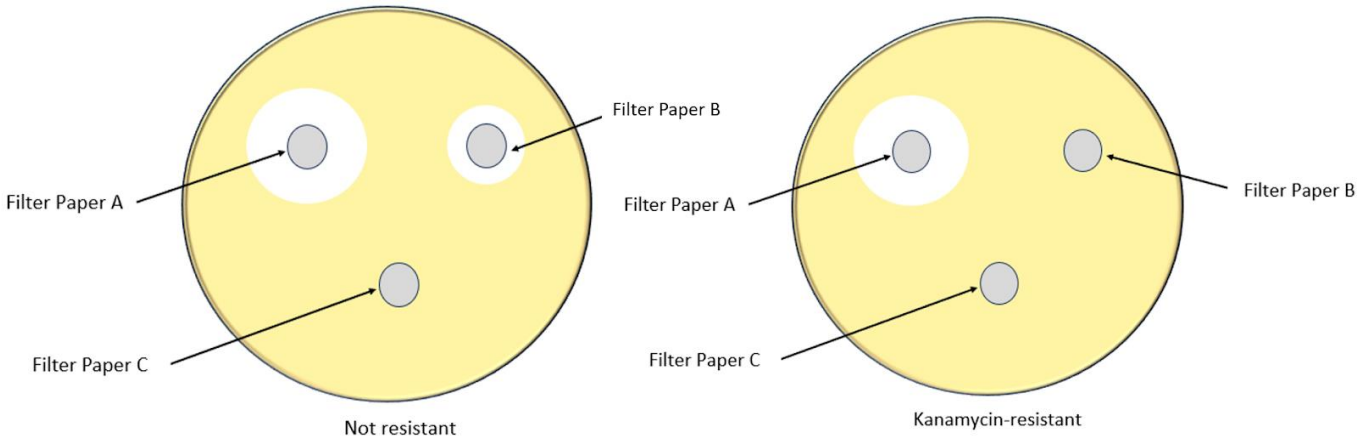
Molecules A and B each only has one hydrophilic head, while Molecule C has two hydrophobic ends. Only Molecule D fits the requirements with two hydrophilic hydroxyl (-OH) groups on the exterior and a hydrophobic alkane chain in the middle.

Easy | Cell Biology

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 CTXφ phages (temperate phage), T_2 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	CTXφ phage
B.	T_2 phage	CTXφ phage	Kanamycin
C.	CTXφ phage	Kanamycin	T_2 phage
D.	CTXφ phage	T_2 phage	Kanamycin

Easy Cell Biology

Answer: **A**

Explanation: First, we need to understand the question. *E. coli* is plated on the entire plate. On the left is *E. coli* not resistant to kanamycin, while on the right *E. coli* is resistant to kanamycin. The addition of the filter papers may kill the *E. coli* cells, resulting in a zone of inhibition which is seen as the white halo around the filter paper.

The filter paper soaked with kanamycin will kill the unresistant *E. coli* but not the resistant one. Thus there should be a zone of inhibition on the left but not on the right, which is filter paper B.

Next, the lytic phage T_2 will infect and kill all the *E. coli* cells by causing them to lyse and release its virions, so a zone of inhibition should be seen in both cases, which is filter paper A.

CTXφ phages are temperate phages. Since incubation was only overnight, they likely only underwent the lysogenic cycle and integrated their genome into the genome of the *E. coli* cells during infection. Thus, no cells were ruptured and killed so there is no zone of inhibition as seen in filter paper C.

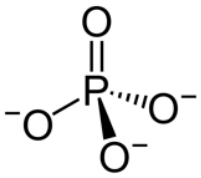
Easy Cell Biology

EC 3: Let’s get this bread

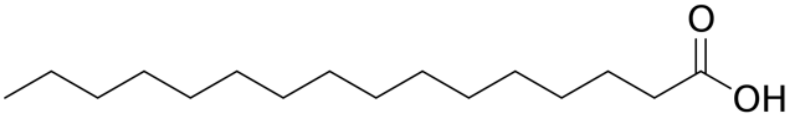
Wonton noodles is a dish of Cantonese origin that is often cooked with pork lard. Avery was eating wonton noodles with soup and noticed that the pork lard in the soup still remained crispy. However, when she added toasted bread pieces (croutons) to the soup, the croutons became soft and no longer crispy.

Which of the following molecules explain this phenomenon?

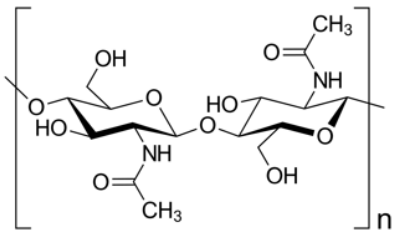
A:



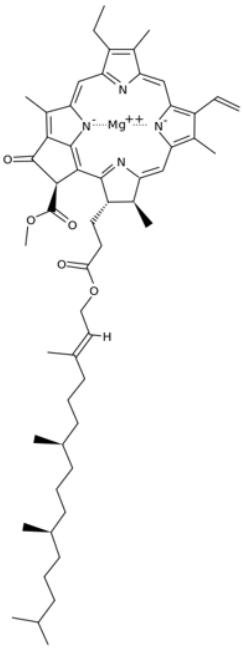
B:



C:



D:



Easy Cell Biology

Answer: **B**

Explanation: It is the high levels of lipids which are hydrophobic and hence do not interact with water that allows pork lard to retain its crispiness. B is thus the answer as it is a fatty acid. A is a hydrophilic phosphate molecule, C is a polysaccharide chitin, and D is chlorophyll.

Easy | Cell Biology

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

★ Easy | Cell Biology

Answer: **A**

Explanation: When a cell is placed in a hypertonic sucrose solution, the water potential of the solution is lower than the cell sap, so water will diffuse out of the cell by osmosis. In converse, in a hypotonic sucrose solution, the water potential of the solution is higher, so water will enter the cell by osmosis.

I. **True.** Water will diffuse out of the red blood cell, causing it to crenate. Crenate is a word used to specifically describe the shrivelling of a red blood cell.
II. **True.** Water will enter the cell via osmosis. Since the animal cell has no cell wall, the cell will swell and lyse.
III. **False.** It is the water molecules that diffuse out of the cell sap and not the sucrose solution that moves into the cell sap. The sucrose molecules are too large to pass through the plasma membrane of the cell.
IV. **True.** Distilled water has a higher water potential than the cell sap so water will enter the cell. However, since the plant cell has a cell wall, there will be wall pressure acting opposite to the turgor pressure (Newton's Third Law) preventing it from lysing. Hence, it will remain turgid.
V. **False.** While distilled water will enter the bacterial cell, the peptidoglycan wall will keep it turgid and prevent it from lysing.
VI. **False.** A naked virion does not have a phospholipid bilayer and a cell membrane as opposed to enveloped virions, so water cannot enter the virion per se to lyse it.

Note: While the definition provided was intended to aid participants in answering the question, it may have inadvertently confused several participants with regard to the differences between "solute potential" and "solute concentration".

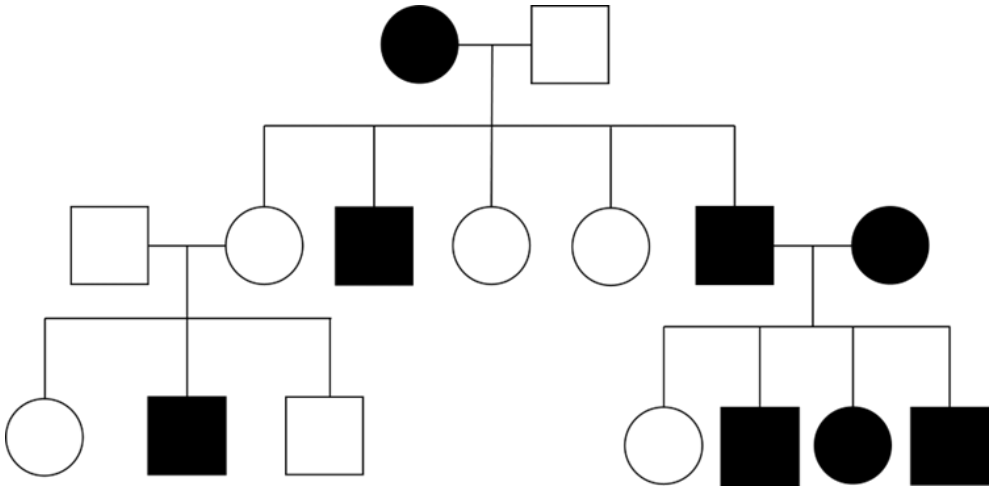
A hypertonic solution has a lower solute potential, higher solute concentration, and lower water potential than the cell sap.

Solute potential (Ψ_S), also known as osmotic potential, is a strictly negative value as long as solutes are present in the solution. This is because it is calculated by $\Psi_S = -iCRT$. Hence, the more solutes there are in the solution, the higher the solute concentration (C) and thus the higher the magnitude of the solute potential ($|\Psi_S|$), so the solute potential is ***more negative****. Therefore, a hypertonic solution has a more negative solute potential than the cell sap, so the* ***solute potential is lower than that of the cell sap****.*

Easy Genetics

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)

Easy Genetics

Answer: **C**

Explanation:

A. If it were X-linked recessive inheritance, all the offspring of the parents who were both affected would also be affected. Hence, it is not X-linked recessive as individual III-4 is unaffected.
B. Same reason as A.
C. The pedigree is consistent with sex-influenced inheritance, where it is autosomal dominant for males (only 1 alleles needed to express the trait) and autosomal recessive for females (2 alleles are needed to express the trait).
D. If it were maternal inheritance, all of the offspring of an affected mother will be affected. However, individual II-2 and II-3 are unaffected.

Easy Genetics

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

Easy Genetics

Answer: **C**

Explanation: The first endosymbiotic event is the engulfing of an α-proteobacterium, which gives rise to the mitochondria. The second endosymbiotic event is the engulfing of a cyanobacterium by the red algae ancestor, which gives rise to the red algae. The third endosymbiotic event is the engulfing of a red algae by *Phagocytosis forlife*.

Easy Genetics

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. $\frac{6}{16}$

Easy Genetics

Answer: **A**

Explanation: Since the genes are not linked, we can consider the probability individually for each gene.

$$P(aaB\_C\_) = P(aa) \times P(B\_) \times P(C\_) = \frac{1}{2} \times \frac{1}{2} \times \frac{3}{4} = \frac{3}{16}$$

Easy Genetics

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.

Easy Genetics

Answer: **B**

Explanation:

A. In general, scientists turn to explanations that point to traits being adaptive before considering that the trait may not be adaptive. Hence, this is not the most likely explanation.
B. This is a valid explanation. If the predator does not have the exact same number of years per reproductive cycle, it will be in sync for the least possible amount of time with that of the cicadas if the length of the cycle is a prime number of years for the cicada, as compared to if the length of the cycle is non-prime. To illustrate an example, say the length of the reproductive cycle of the predator is 4 years. If the length of the reproductive cycle of the cicadas is 12 years, the predator can sync its reproductive cycle with that of the cicadas so that they are at the optimal age every time the cicadas emerge. By contrast, if the length of the reproductive cycle of the cicadas is 13 years, they will only sync up once every 52 years.
C. If this explanation is true, there is no reason why the number of years must be exclusively prime.
D. Cicadas are herbivores and there is no indication that such 13- or 17-year cycles exist for plants.

Easy Ecology

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

Easy Ecology

Answer: **B**

Explanation: Vampire bats help each other because of reciprocal altruism, meaning that they feed their peers with the expectation that their favour will be returned in the future. This evolutionary system is aided by the fact that vampire bats can often identify those who helped them in the past **(contingent on future encounter)**.

Meerkats are even more likely to help each other, given that they are related. While giving the warning call may decrease its direct fitness, it will overall raise its inclusive fitness via its relatives **(immediate raising of inclusive fitness)**.

Lastly, sterile worker bees are the most altruistic in comparison to the other 2 species, given that they are sterile and hence have a direct fitness of 0. Hence, the behaviour that evolved is one that maximises the survival of the colony, specifically the reproduction of the queen bee, through which the worker bees' inclusive fitness is derived.

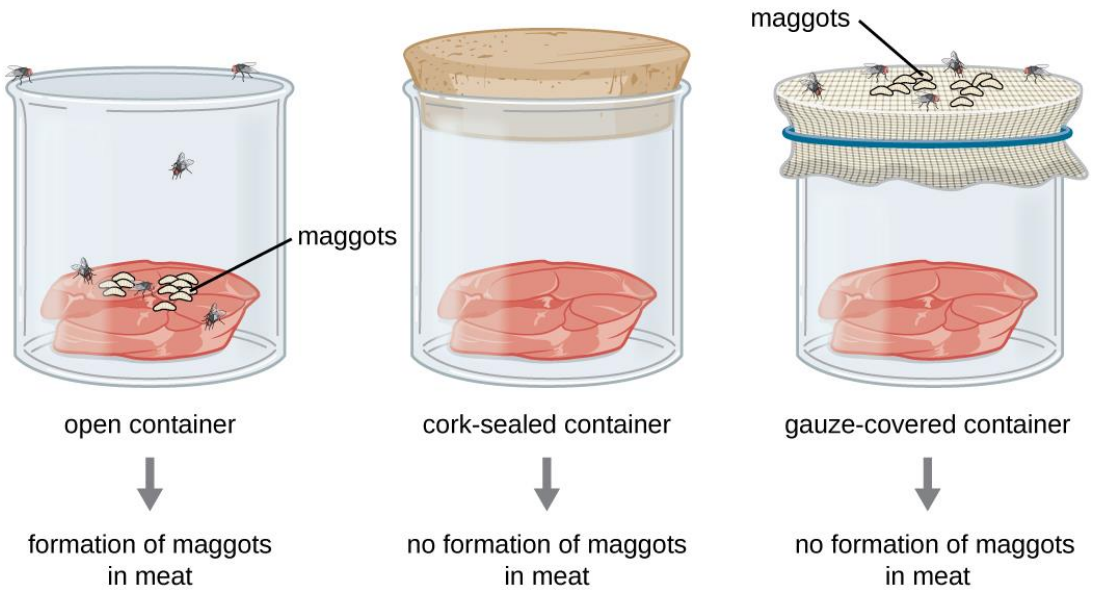
Easy Ecology

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

Easy Ecology

Answer: **D**

Explanation: We want to prove that maggots do not spontaneously arise from meat. Hence, our experimental set up should be meat that has any contact to flies in the environment cut off to prevent flies from laying the eggs on the meat, so that we can be sure that any maggots that appear on the meat is due to spontaneous generation and not due to the flies (Gauze-covered container).

The negative control is the cork-sealed container as we want to block out all the air in the meat to show that the meat does not already contain maggots as the maggots will need oxygen to live. It serves as the negative control and is intended to produce a negative result.

The positive control is the open container to show that maggots can grow on the meat by some mechanism so that the lack of maggots in the experimental set up can be said to be due to the lack of spontaneous generation and access of the flies to the meat and not due to the meat being inhospitable for the maggots.

Credits:

Parker, N., Schneegurt, M., Tu, A.-H. T., Lister, P., & Forster, B. M. (n.d.). *3.1 Spontaneous Generation - Microbiology*. OpenStax. https://openstax.org/books/microbiology/pages/3-1-spontaneous-generation?query=redi&target=%7B%22index%22%3A0%2C%22type%22%3A%22search%22%7D#fs-id1172098647894

Easy Ecology

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 invariantly 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

Easy Ecology

Answer: **A**

Explanation:

I. The mother can choose not to catch the toddler. FAPs are usually not observed in humans. This is more of a reflex action as the mother is able to stop the process of catching the toddler.

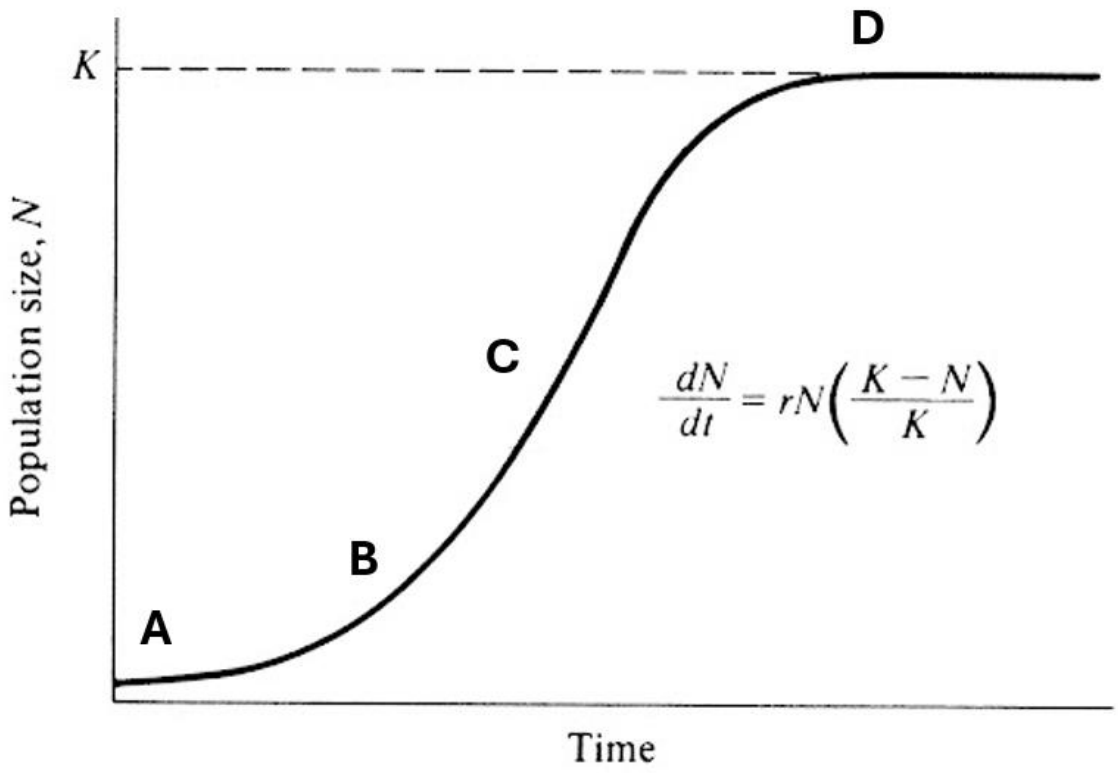
II. This is not a series of actions. It is more likely menotaxis.

III. This is a classic example of a FAP. The egg-like object (tennis ball) near the nest triggers the series of actions of rolling it back.

Easy Ecology

EE 4: Shortest question ever

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



Easy Ecology

Answer: **A**

Explanation:

$$Gradient = Population\ growth\ rate, \frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

$$Population\ growth\ rate\ per\ capita, \frac{1}{N} \times \frac{dN}{dt} = r\left(\frac{K-N}{K}\right)$$

To maximise population growth rate per capita, we need to maximise $\frac{K-N}{K}$ since r is a constant. $\frac{K-N}{K}$ is maximally 1, when $N = 0$ i.e. when the population is as small as possible. Hence the answer is A, where the population is minimal.

Hope you did not get tricked!

Medium Animals

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:

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

What is the HOMA-β value of someone with a fasting blood glucose level of 5000 µmol/L and a fasting insulin level of 15µU/dL?

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

Medium Animals

Answer: **B**

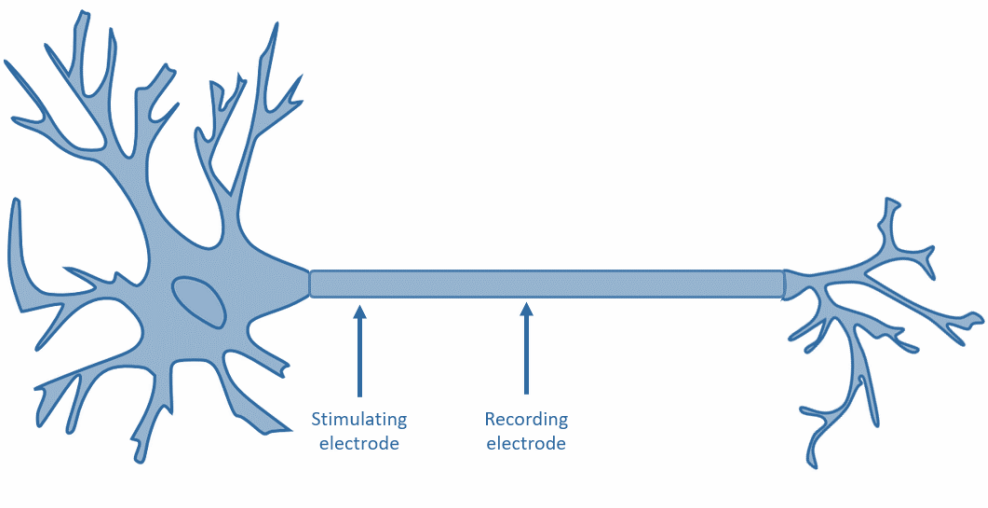
Explanation: Based on the given equation, we can get:

$$HOMA-\beta = 20 \times \frac{15 \times \frac{0.001}{0.1}}{5 - 3.5}\ \% = 2\%$$

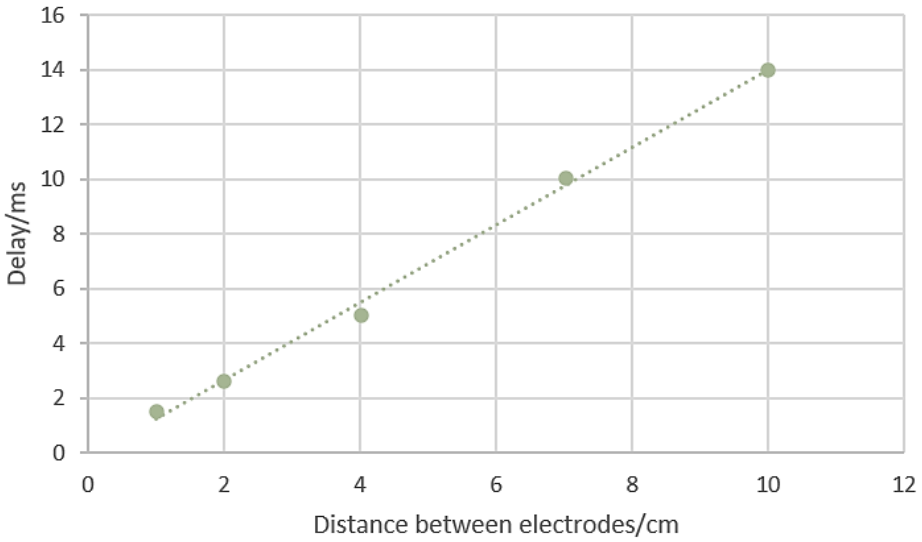
Medium Animals

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.



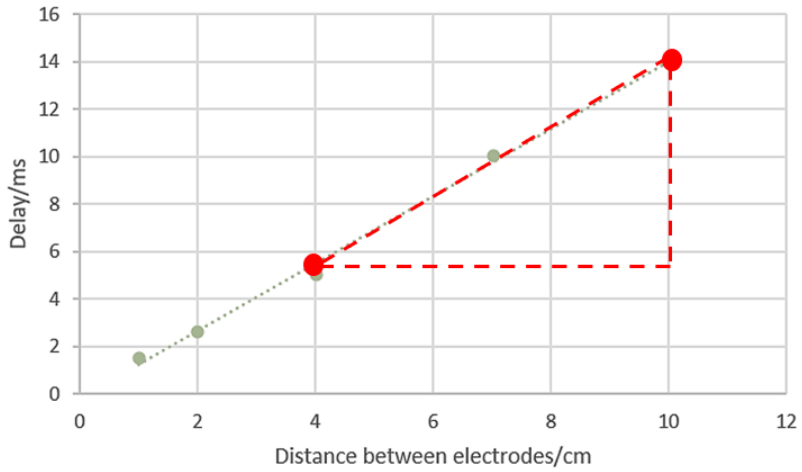
Which of the following speed is the closest to the average speed of conduction in this axon?

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

Medium Animals

Answer: **C**

Explanation: The speed of conduction can be found by the **reciprocal of the gradient** of the line. This is because we want to find $\frac{ds}{dt}$ (distance over time), but the gradient of the line is $\frac{dt}{ds}$ as time is on the y-axis and distance is along the x-axis. We use the points on the line marked in red below i.e. (10, 14) and (4, 5.5). Pay attention to the units.



$$Speed^{-1} = \frac{(14 - 5.5)ms}{(10 - 4)cm} = \frac{9.5ms}{6cm} = \frac{9.5 \times 10^{-3}s}{6 \times 10^{-2}m} = 0.158sm^{-1}$$

$$Speed = \frac{1}{0.158} = 6.33ms^{-1} = 7ms^{-1}$$

Medium Animals

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

Medium Animals

Answer: **A**

Explanation: The unionised form HX is less hydrophilic than ionised form X- and will pass through the cell membrane more readily. The stomach, with the lowest pH, will shift the equilibrium toward unionised HX the most. Hence, the stomach is the likely main absorption route for drug HX.

Medium Animals

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

Medium Animals

Answer: **B**

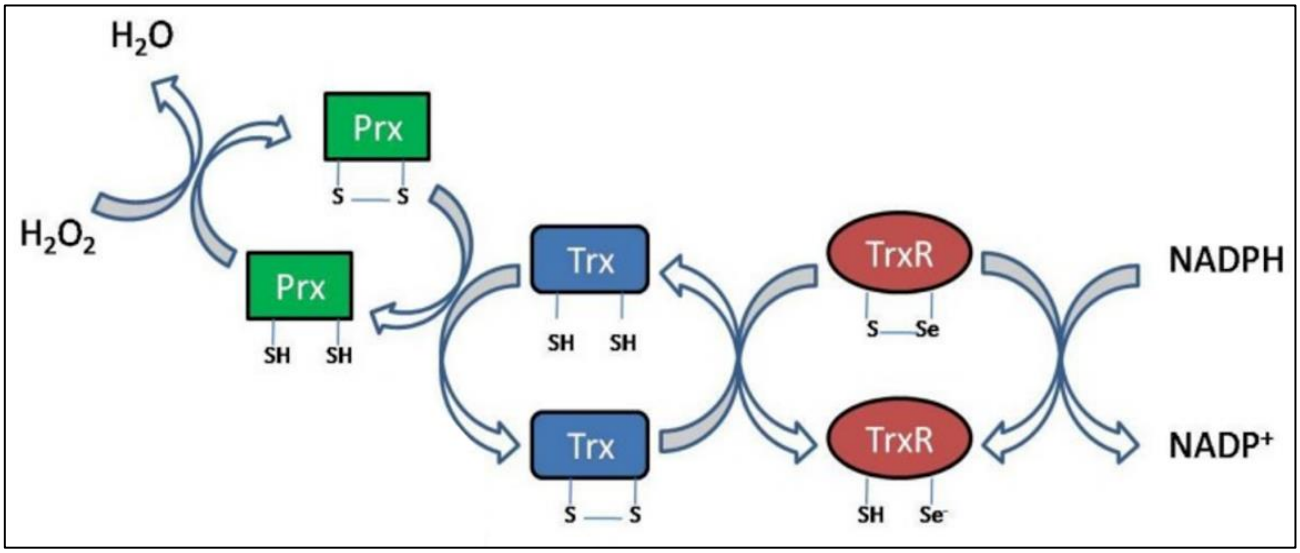
Explanation: If the volume is 150mL, which is 1.5×10^{-4} litres, then the sphere has a radius of approximately 0.033m, which is around 3.3cm. 90 mmHg is around 12.0 kPa, so the wall stress can be calculated as:

$$s = \frac{PR}{2t} = \frac{(12.0)(3.3)}{2 \times 1.5} = 13.2\ kPa$$

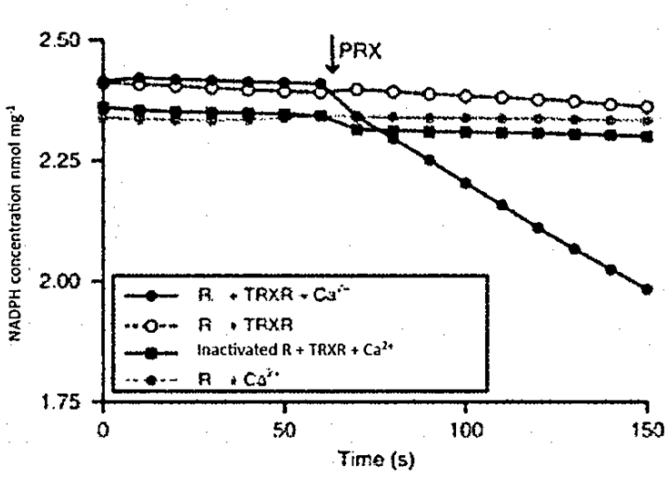
Medium Plants

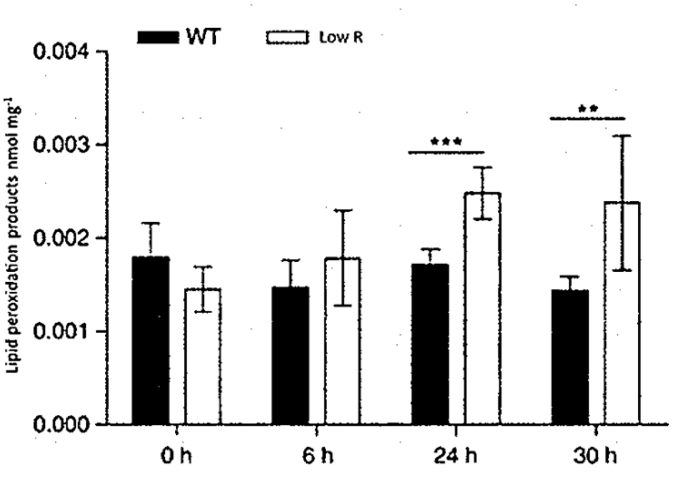
MP 1: It's hot in here

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.





Medium Plants

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

Medium Plants

Answer: **B**

Explanation:

A. **True.** The NADPH concentration remained constant in the absence of Ca^{2+} and only fell when Ca^{2+} was present.
B. **True.** Depletion of **R** causes a rise in lipid peroxidation products over time, which is a biomarker of oxidative stress in plants.
C. **False.** Comparing the first and third lines in the legend, we see that **R** causes a fall in NADPH concentration. Thus, less NADPH is prevent to reduce TrxR so TrxR is reduced by the reduction of Trx. This increases the rate of the redox cycle of Trx so more Trx becomes oxidised with the concomitant reduction of Prx. Thus, reduction of Prx increases.
D. **True.** Depleting **R** keeps NADPH levels high without increasing the levels of ATP. Hence, cyclic phosphorylation will increase the increase the levels of ATP without increasing the levels of NADPH so that there are balanced levels of NADPH and ATP for the Calvin Cycle.

Credits:

Trx redox system: Modified from Karlenius, T. C., & Tonissen, K. F. (2010). Thioredoxin and cancer: A role for thioredoxin in all states of Tumor Oxygenation. *Cancers*, *2*(2), 209–232. https://doi.org/10.3390/cancers2020209

R graph: Modified from Hochmal, A. K., Zinzius, K., Charoenwattanasatien, R., Gäbelein, P., Mutoh, R., Tanaka, H., Schulze, S., Liu, G., Scholz, M., Nordhues, A., Offenborn, J. N., Petroutsos, D., Finazzi, G., Fufezan, C., Huang, K., Kurisu, G., & Hippler, M. (2016). Calredoxin represents a novel type of calcium-dependent sensor-responder connected to redox regulation in the chloroplast. *Nature Communications*, *7*(1). https://doi.org/10.1038/ncomms11847

Medium Plants

MP 2: A Tall Plant

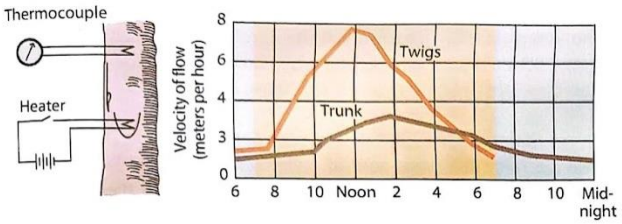
Dr Lim is carrying out a physiological analysis of volume flow rate in the xylem at a fixed height throughout the day. She has already watered the plant with radiolabelled water for radioisotope tracing. As time passes towards noon, the volume flow rate measured strictly increases. Relative to the volume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

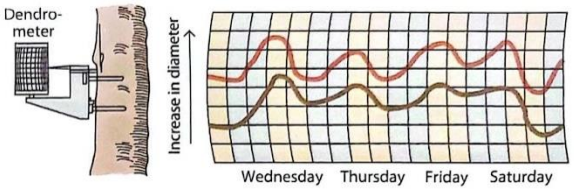
Medium Plants

Answer: **B**

Explanation: The increase in velocity is due to transpiration as increased sunlight towards noon increases evapotranspiration. This results in increased velocity in the upper parts of the stem first, resulting in increased tension in the water column, causing an increased velocity in the lower parts of the stem later.



30–13 Measuring velocity of sap flow A small heating element inserted into the xylem heats the ascending sap for a few seconds. A thermocouple above the heating element records the passing wave of heat. The experimenter times the interval between these two events. As shown in the graph, in the morning the sap begins to increase its velocity of flow first in the twigs and then in the trunk. In the evening, velocity diminishes first in the twigs and then in the trunk.



30–14 Fluctuations in tree trunk diameter A dendrometer (left) records small daily fluctuations in the diameter of a tree trunk at two different heights. As shown in the graph, in the morning, shrinkage occurs in the upper trunk slightly before it occurs in the lower trunk. These data suggest that transpiration from the leaves "pulls" water out of the trunk before it can be replenished from the roots. The gray strips signify nighttime, and the yellow strips represent daytime.

Credits:

Figures 30-13 and 30-14 in the explanations were taken and scanned from Raven Biology of Plants (8th ed.).

Evert, R., Eichhorn, S., & Raven, P. (2013). *Raven Biology of Plants* (8th ed.). W.H. Freeman and Company Publishers.

Medium Plants

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

Medium Plants

Answer: **B**

Explanation: By analysing the different treatments, we can see that a low ratio of A:B causes the callus to develop roots (Treatment 1), while a high ratio of A:B causes the callus to develop shoots (Treatment 3). Notwithstanding, the lack of hormone A or hormone B causes no growth to occur (Treatment 2 and 4). Moreover, intermediate ratios causes growth with no differentiation (Treatment 5).

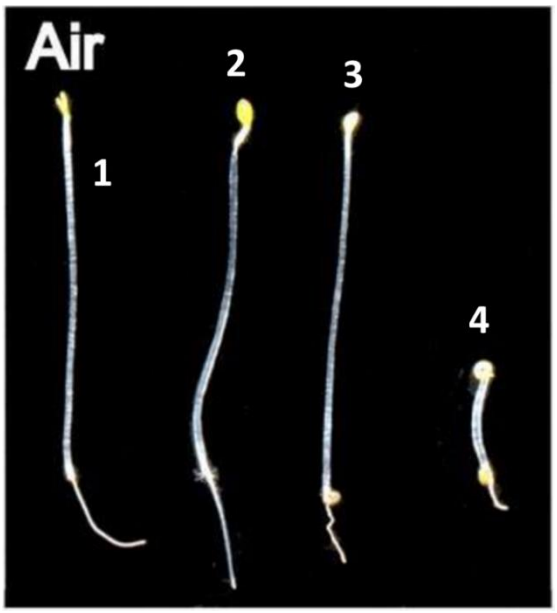
We can deduce that Hormone A is cytokinin and Hormone B is auxin. Auxin is produced in the shoot apical meristems, while cytokinin is produced in the root apical meristems. Hence, a low ratio of A:B meaning that more cytokinin than auxin is produced would signal to the plant that there is an imbalance in the growth of the shoots, and thus will act as a signal to the shoots to increase in growth.

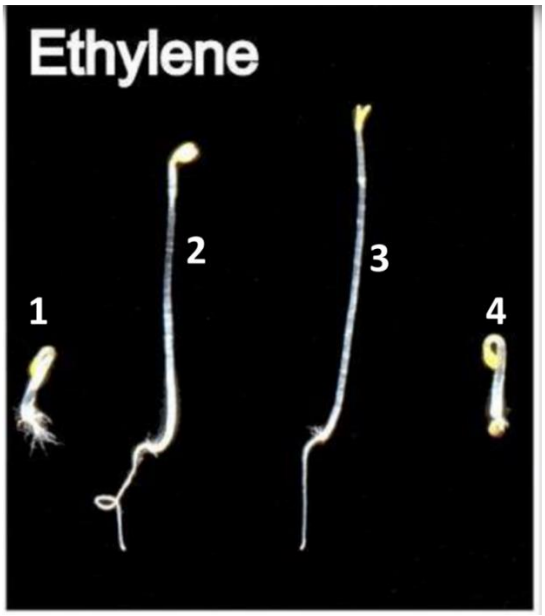
I. **True.** As explained above.
II. **False.** As explained above.
III. **True.** As mentioned, in the absence of hormone B, no growth can even occur, let alone differentiation.
IV. **True.** The callus cells have already developed roots. The low hormone A:B ratio will induce the formation of roots, which will turn them into plantlets.
V. **False.** They developed from the same plant and hence genetically-identical parenchyma cells, so they will be genetically identical.

Medium Plants

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

Medium Plants

Answer: **D**

Explanation: Plants respond to ethylene by carrying out the triple response, which comprises shortened and thickened hypocotyl, an inhibition of root elongation, and the formation of an exaggerated apical hook. We see this in plant 4 in air (absence of ethylene), which means it is the constitutive-triple response mutant and the pathway is active even in the absence of ethylene. Plant 1 carries out the triple response in the presence of ethylene, but not air, so it is normal. Plant 2 and 3 are phenotypically indistinguishable, and do not carry out the triple response in the presence of ethylene, meaning that the triple response pathway is defective and hence they are either an ethylene-insensitive mutant or ethylene-receptor mutant in no particular order.

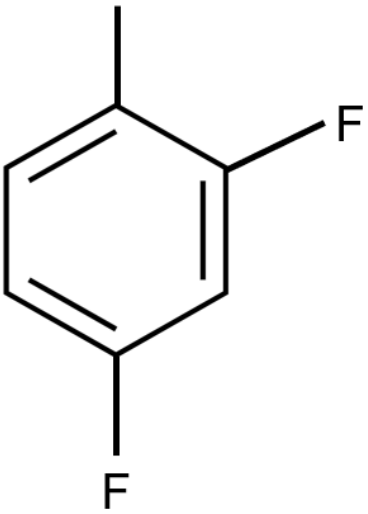
Credits:

Modified from Schaller, G. E., & Kieber, J. J. (2002). Ethylene. *The Arabidopsis Book*, *1*. https://doi.org/10.1199/tab.0071

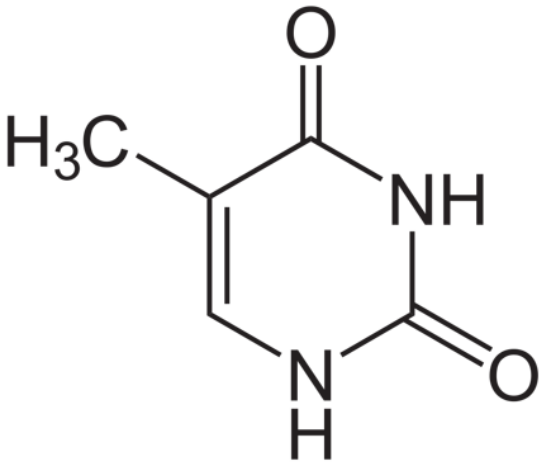
Medium Cell Biology

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

Medium Cell Biology

Answer: **D**

Explanation: In the 2,4-difluorotoluene base there are 7 carbons, while there are 5 in the thymine base. In the DNA triplet, there is the phosphate head, deoxyribose pentose sugar (5-carbon), and the nitrogenous base. Hence, the total number of carbons can be calculated as:

$$C_{phosphate} + C_{pentose} + C_{base} = 0 + (5 + 5 + 5) + (7 + 7 + 5) = 34$$

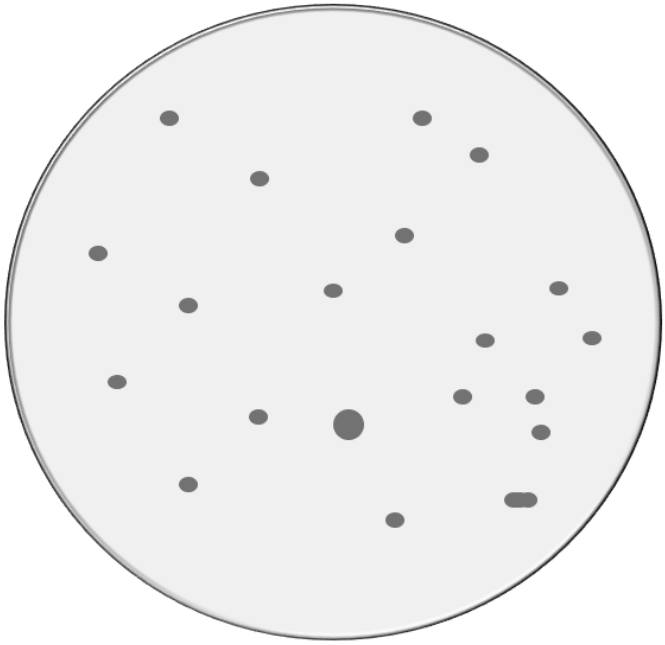
Medium Cell Biology

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 40µL 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

Medium Cell Biology

Answer: **D**

Explanation: We first count that there are 20 colonies on the agar plate. Since this is in 3mL of the resultant solution, the amount of CFU per mL in the resultant solution is $\frac{20}{3}$ CFU per mL.

Since there is a dilution of 20x six times, the amount of CFU before these six dilutions is:

$$\frac{20}{3} \times 20^6 \text{ CFU per mL}$$

Thus, $\frac{20}{3} \times 20^6$ CFU per mL is present in the 10mL after dissolving the sample solution. Hence, there is in the 40µL of the sample solution $\frac{20}{3} \times 20^6 \times 10$ CFU.

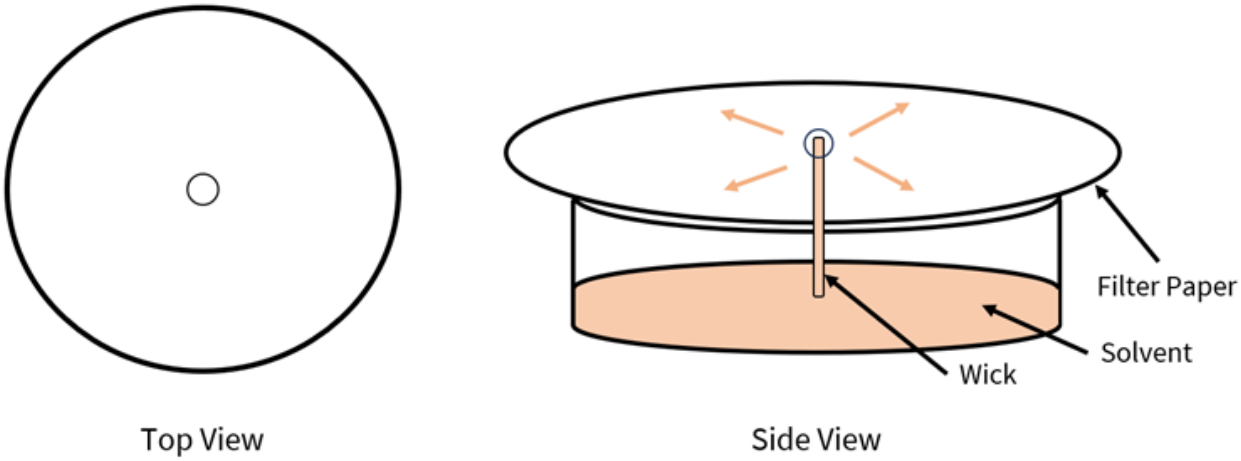
Hence the number of CFU per mL in the sample solution is:

$$\frac{\frac{20}{3} \times 20^6 \times 10}{40 \times 10^{-3}} = 1.07 \times 10^{11} \text{ CFU per mL}$$

Medium | Cell Biology

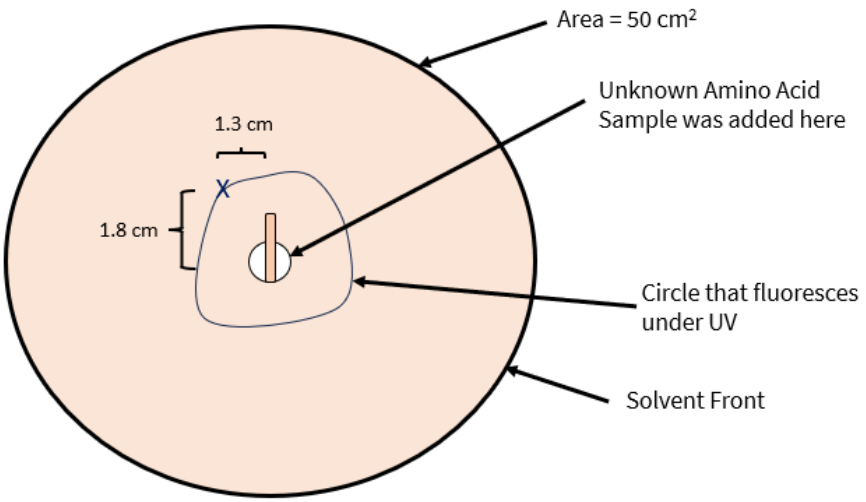
MC 3: Roly-Poly

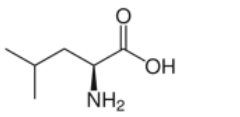
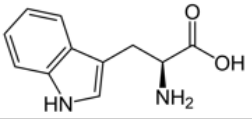
A type of chromatography is radial chromatography which is similar to thin-layer chromatography. The solvent is drawn up the wick and travels radially outwards through the filter paper.



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.



P	
Q	

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

Medium Cell Biology

Answer: **B**

Explanation: Similar to thin-layer chromatography, to calculate the R_f we need the distance travelled by the amino acid and the distance travelled by the solvent. We can calculate this as seen in the figure below.

The distance travelled by the solvent can be the radius of the filter paper. Hence, the radius is:

$$Radius = \sqrt{\frac{50}{\pi}}$$

The distance travelled by the amino acid can be found by Pythagoras' Theorem:

$$Distance\ travelled = \sqrt{(1.8)^2 + (1.3)^2}$$

Hence the R_f can be calculated as:

$$R_f = \frac{\sqrt{(1.8)^2 + (1.3)^2}}{\sqrt{\frac{50}{\pi}}} = 0.56$$

Since the preamble stated that the amino acid fluoresces under UV light, it is likely one of the aromatic amino acids with a benzene ring. Hence, the amino acid is Q.

Medium Cell Biology

MC 4: Cell division = Multiplication

Microtubules are made of αβ tubulin heterodimers. Suppose some αβ 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 αβ 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 αβ tubulin heterodimers occurs near the chromosome
B. Microtubular breaks cause unexpected shortening of the kinetochore microtubules
C. Most of the depolymerisation of αβ tubulin heterodimers occurs near the MTOC
D. Random polymerisation and depolymerisation rearranges the fluorescently tagged αβ tubulin heterodimers within the kinetochore microtubules

Medium Cell Biology

Answer: **A**

Explanation: Since the fluorescently tagged αβ tubulin heterodimers are found closer to the chromosome than the MTOC, it means that the αβ tubulin heterodimers lost are from the chromosome end, instead of the MTOC end. B is false as microtubular breaks are unlikely as it requires the breaking of a large number of noncovalent bonds between αβ tubulin heterodimers. D is false as random polymerisation and depolymerisation only occurs at the ends of the microtubule and would not rearrange the αβ tubulin heterodimers in the middle of the microtubule.

Medium Genetics

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^o).

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^o	850
β^+/β^o	100

What is the frequency of the β^+ allele?

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

Medium Genetics

Answer: **D**

Explanation: Since the population is in Hardy-Weinberg Equilibrium and there are three alleles, we know that:

$$p + q + r = 1$$

Letting p be β, q be β^+, and r be β^o, we get:

$$2pq = \frac{1700}{10000} \Rightarrow pq = 0.085 \Rightarrow p = \frac{0.085}{q}$$

$$2pr = \frac{850}{10000} \Rightarrow pr = 0.0425 \Rightarrow p = \frac{0.0425}{r}$$

$$2qr = \frac{100}{10000} \Rightarrow qr = 0.005 \Rightarrow r = \frac{0.005}{q}$$

Solving simultaneously, we get:

$$\frac{0.085}{q} = \frac{0.0425}{r}$$

$$\frac{0.085}{q} = \frac{0.0425q}{0.005}$$

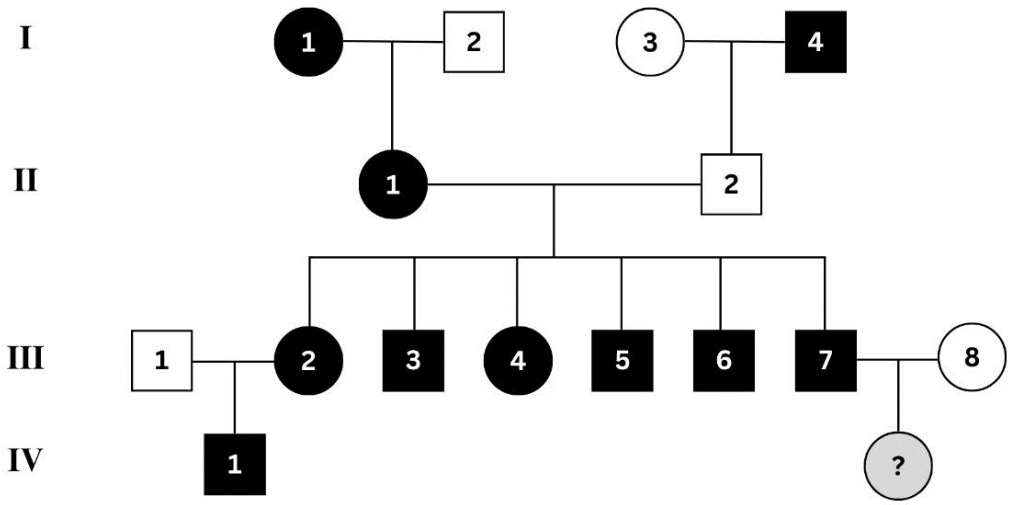
$$q^2 = 0.01$$

$$q = 0.10$$

Medium Genetics

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

Medium Genetics

Answer: **A**

Explanation: Point mutation implies only one gene is affected. If the disease was due to dominant-recessive allele relationships, then the mutated allele would be dominant, and II-1 has to be heterozygous. However, all six offspring of II-1 and II-2 are afflicted with the disease, along with the offspring of III-1 and III-2, which is extremely unlikely for a heterozygous-homozygous recessive cross (approximately a 0.8% chance).

Hence, point mutation likely lies in the non-chromosomal mitochondrial DNA. Mitochondrial DNA in humans is passed down from the ovum to the offspring. Female III-8 is not genetically related to the family and does not carry the mutation. Hence, the offspring of III-7 and III-8 has a 0 probability of attaining the disease.

Medium Genetics

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 vaL	**Presence of vaL**
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 vaL	**Presence of vaL**
Mutant 6	Blue	Blue

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

I. In the presence of vaL, the colour of the WT cells should be green.
II. Mutant 1 has a mutation in enzyme A.
III. Mutant 3 has a mutation in the promoter.
IV. Mutant 4 definitely has a mutation in the operator.
V. 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

Medium Genetics

Answer: **D**

Explanation: Let's first analyse the operon. When the operon is active, enzyme A will convert vermonin to a blue compound, while enzyme B will convert it to a yellow compound. They thus mix together to form a green colour. We can deduce this because there is the green phenotype in the table.

Since coloured phenotypes are only seen in the absence of vaL, we can deduce that **in the absence of vaL the operon is active**, so the coloured compounds can be produced. Thus, the WT phenotype should be Green and Colourless respectively. **(A is false.)**

Next, we see in mutant 1 that instead of green, it is yellow in the absence of vaL. Therefore, enzyme A is likely inactive, so no blue compound was produced, so it remained yellow. **(B is true.)**

Mutant 3 could have a mutation in the promoter, so the entire operon is never transcribed, so no enzyme is produced, thus it remains colourless. **(C is true.)**

We cannot tell if Mutant 4 is the one with a mutation in the operator with certainty because Mutant 2 may be the one with the mutation in the operator and Mutant 4 has a mutation in the regulatory gene. **(D is false.)**

A loss-of-function mutation in the regulatory gene will cause the operon to continue to be transcribed even in the presence of vaL. With enzyme B also being inactive, no yellow compound is produced, thus the phenotype is blue in both cases. **(E is true.)**

Medium Genetics

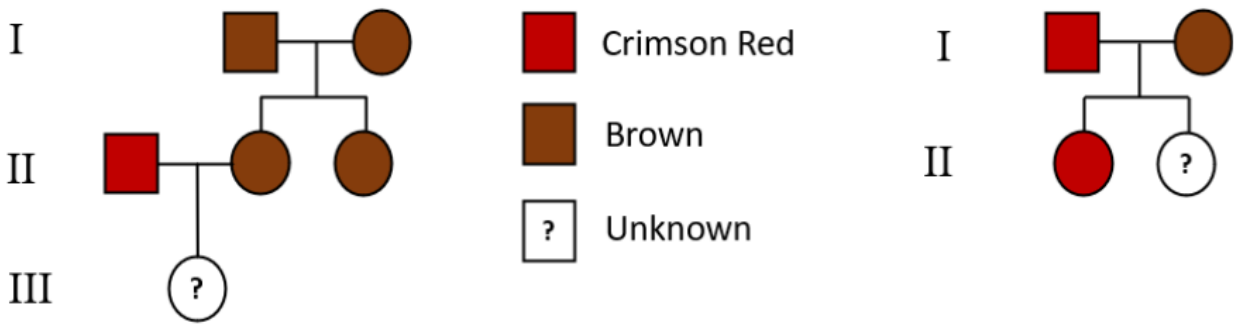
MG 4: I hate ants

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.



Colony 1 **Colony 2**

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 Genetics

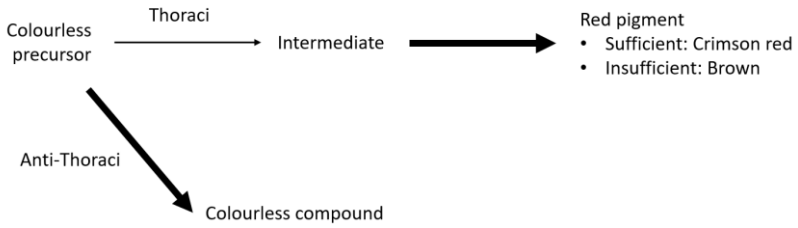
Which of the above statements are true?

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

Medium Genetics

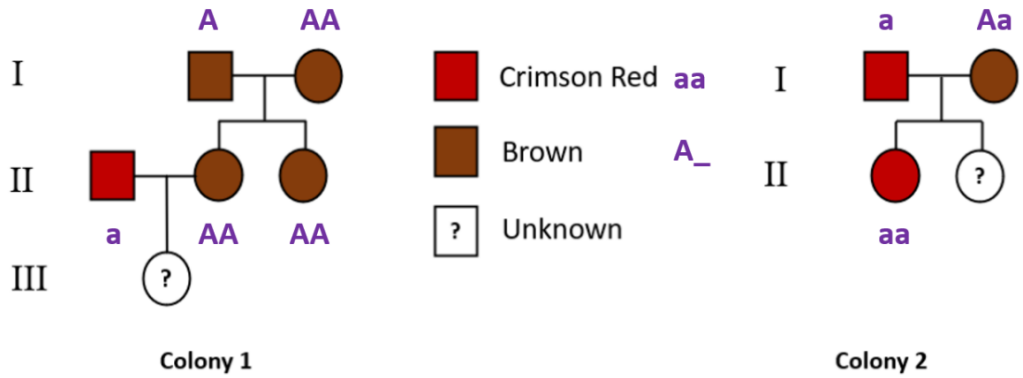
Answer: **C**

Explanation: From the preamble, we can deduce that ants have a haplodiploid sex-determination system. Males are haploid and develop from a female, while females are diploid and develop from a male and female. **Thus, males only have one allele of each gene.** The Thoraci pathway can be seen below.



We can tell that in heterozygotes, they have both Thoraci and anti-Thoraci enzymes. Since the action of anti-Thoraci is faster, there will be insufficient red pigment to accumulate, so the thorax remains brown and the **dominant phenotype is brown**.

With the gene relationship and haplodiploidy settled, we can identify the genotypes in the pedigree using the gene *A/a*. Remember that the preamble stated that female I-2 of **colony 1** is homozygous.



I-2 of **colony 2** is heterozygous as one of the progeny is recessive homozygous, so she must have had a recessive *a* allele to pass down to the progeny.

I. **False.** Stated above.
II. **True.** Stated above.
III. **True.** There is a 0% chance III-1 will be crimson red. III-1 can only be a female as it develops from a mother and father. Hence, the female is diploid and will have genotype *Aa* and will be brown.
IV. **False.** III-1 has a coefficient of relatedness of 0.5 with II-2 and hence a coefficient of relatedness of 0.25 with I-1.
V. **False.** A male cannot be produced from the mating of a male and female.

Medium Ecology

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:

- $CO_{2\ (dissolved)} + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
- $HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$
- $Ca^{2+} + CO_3^{2-} \rightleftharpoons CaCO_3$

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.

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

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

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

Medium Ecology

Answer: **A**

Explanation: Note the question requires you to select the false statements.

I. **False.** Calcareous depositions can accumulate above the carbonate saturation horizon.

II. **False.** The rise in atmospheric carbon dioxide will cause an increase in dissolved carbon dioxide and thus H_2CO_3 which will dissociate to H^+ and HCO_3^-. To counter the increase in H^+ ions, the dissolution of $CaCO_3$ will be favoured. As such, the carbonate saturation horizon will be higher, and calcareous species will only be able to survive at shallower depths.

III. **True.** Lower temperatures and increased pressures at lower depths increase the solubility of $CaCO_3$. Similarly, at lower depths, generally there are higher levels of salt as saline water is denser. During the cycling of water, the denser saline water on the top is replaced by less dense fresh water at the bottom. In the presence of NaCl, the solubility of $CaCO_3$ increases to a maximum.

Medium Ecology

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*)

Medium Ecology

Answer: **B**

Explanation: There is clearly no pattern of mating between each individual, suggesting that this animal does not form pair bonds. Hence, this animal is promiscuous and the only animal of the four that is promiscuous is the White-handed Gibbon (*Hylobates lar*).

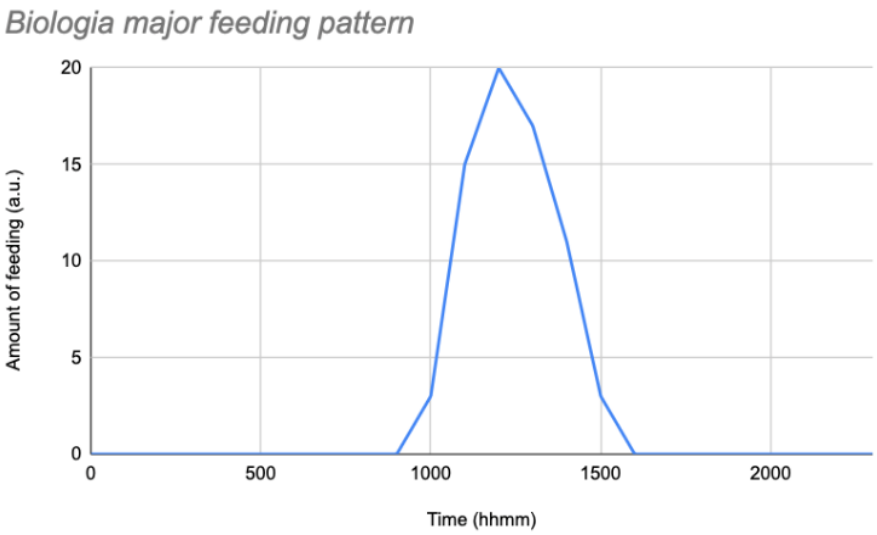
A. Polygyny.
B. Promiscuity.
C. Polygynandrous. Not the same as promiscuity as chimpanzees only mate with a few of the opposite sex.
D. Monogamy.

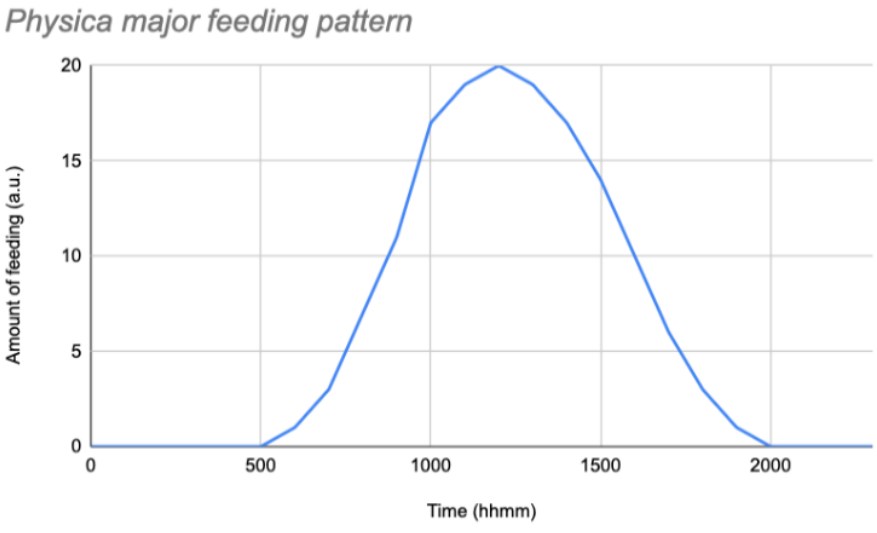
Medium Ecology

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.





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.

Medium Ecology

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

Medium Ecology

Answer: **C**

Explanation:

I. **True.** *Physica major* has a wider feeding window than *Biologia major*. Suppose *Biologia major* outcompetes *Physica major* and *Physica major* does not competitively displace its feeding pattern. *Physica major* will have feeding windows from 0500-0900, and 1600-2000. Whereas, suppose *Physica major* outcompetes *Biologia major* and *Biologia major* does not competitively displace its feeding pattern. *Biologia major* does not have a feeding window that is not occupied by *Physica major*. Hence, *Biologia major* is more likely to be competitively excluded.

II. **Not necessarily true, and thus false.** There is insufficient evidence to show whether each species has the capability to competitively displace their feeding pattern.

III. **True.** Competitive displacement is the result of interspecific competition. When the interspecific competition is quelled, the surviving species will likely return to its original feeding pattern.

IV. **True.** The effects of interspecific competition and competitive displacement may differ from habitat to habitat.

Medium Ecology

ME 4: The Emoji Question

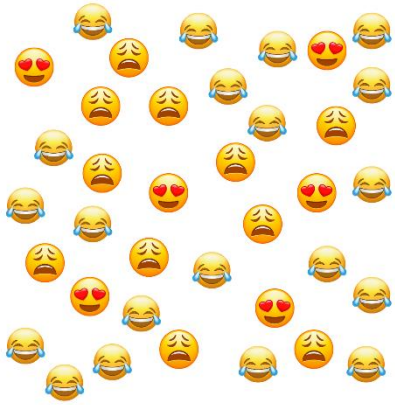
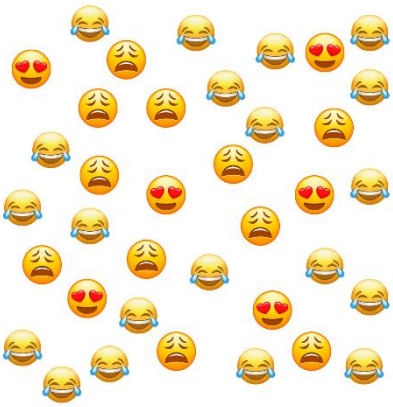
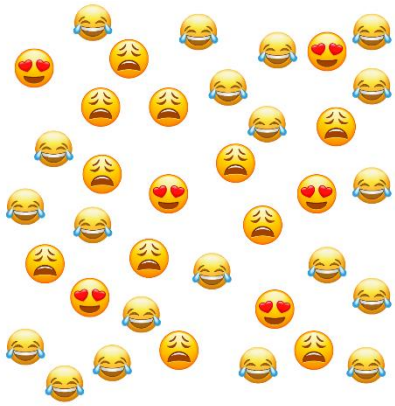
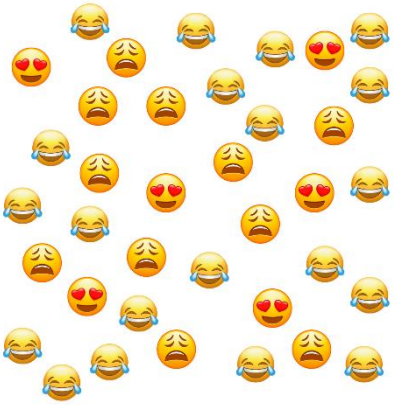
Six species, each represented by an emoji, are the only species that live in a fictitious habitat. The habitat is prone to occasional destruction due to a nearby volcano that resets parts of the habitat into secondary succession.

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?

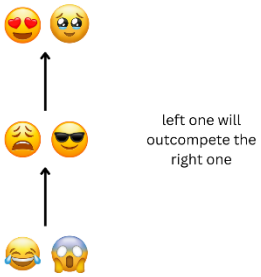
Medium Ecology

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

Medium Ecology

Answer: **A**

Explanation: These are the only six species in the habitat. Hence, the three trophic levels are primary producers, primary consumers, and secondary consumers.

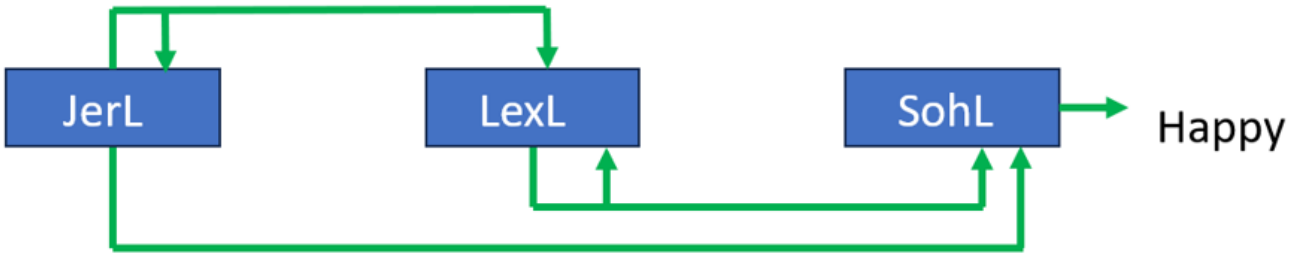


Zone 2 will exhibit competitive exclusion as the secondary consumers share the same niche, and the primary consumers share the same niche. One species will outcompete the other, leading to low species richness. Zone 1 will therefore show a higher species richness than zone 2, a phenomenon known as the intermediate disturbance hypothesis, as seen in options A and C. Zone 3 will undergo secondary succession after the fire, which, 100 years from the catastrophic event, will likely have primary producer growth, as seen in options A and B.

Hard Animals

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

Hard Animals

Answer: **C**

Explanation:

I. **True.** The system has 2 stable states. A. No expression of Live, Laugh, Love. B. Sustained expression of Live, Laugh, Love, as Live and Laugh acts as activators to increase expression of genes *JerL* and *LexL* which codes for the respective transcription factors.

II. **True.** Laugh acts as an activator to increase expression of the gene *LexL* which codes for Laugh, leading to sustained expression of Laugh. Laugh then acts as an activator to increase expression of the gene *SohL* which codes for Love, leading to sustained expression of Love.

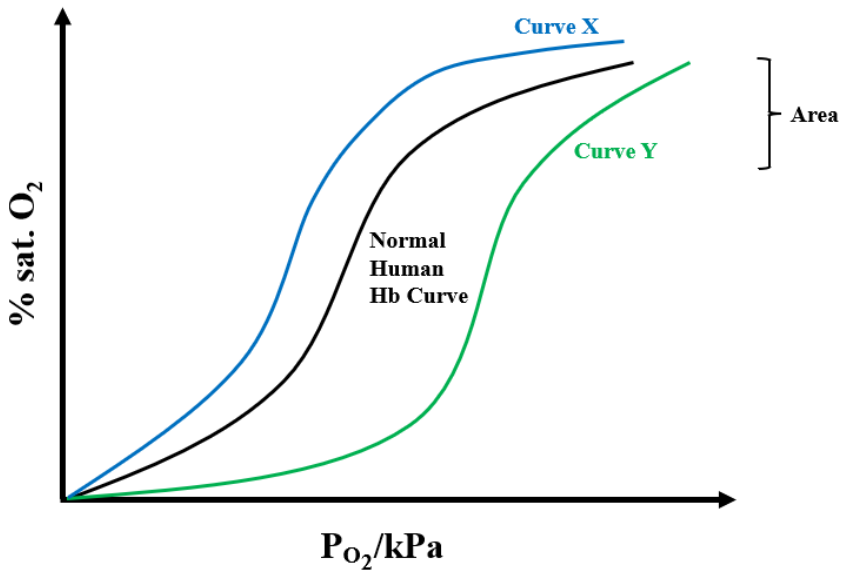
III. **True.** Transcription factors are *trans* regulatory elements and can affect expression on both homologous chromosomes as they are diffusible. This is in contrast to enhancer and silencer DNA sequences which are *cis* regulatory elements and can only affect expression of the gene on the chromosome which it is on.

IV. **False.** Love does not act as an activator to increase expression of the gene *SohL* which codes for Love, so there is no sustained activity of Love.

Hard Animals

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.

I.	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.
II.	Increasing the red blood cell count of humans will shift the normal curve to resemble curve Y.
III.	Hypocarbia (low levels of carbon dioxide in the body) will shift the normal curve to curve X.
IV.	The “Area” indicated by the parenthesis on the normal Hb curve indicates the O_2 released to the exercising tissues.
V.	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?

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

Hard Animals

Answer: **C**

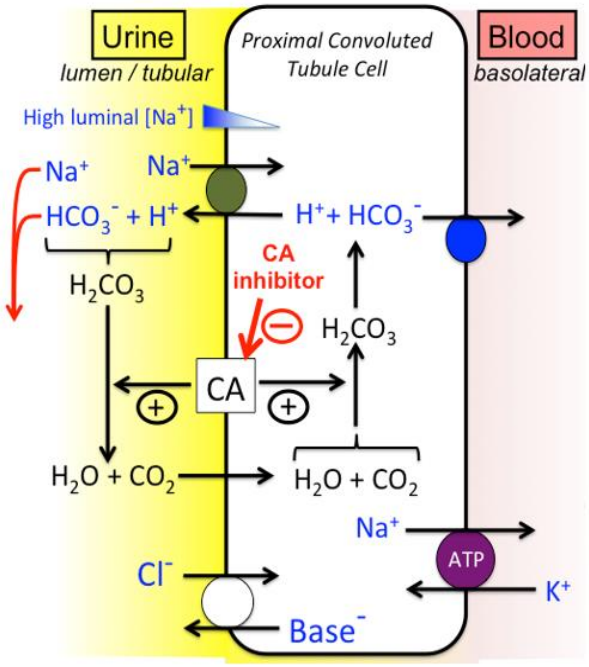
Explanation: To read the oxygen-dissociation curve, we need to understand that haemoglobin binds to oxygen with different affinities at different partial pressures of oxygen. When there is more oxygen, the partial pressure of oxygen i.e. P_{O2} rises, and the affinity of haemoglobin to oxygen rises. When the curve moves rightwards, we can draw a vertical line at a certain level of P_{O2} and mark the intersection of the curve and the line to see the affinity of haemoglobin to oxygen. We can thus see that as the curve shifts to the right, the affinity of haemoglobin to oxygen falls at all points.

I. **False.** The rest of the statement is true except for the fact that haemoglobin has no covalent bonds. The presence of covalent bonds will prevent haemoglobin from changing in conformation during cooperativity, which is why haemoglobin lacks such bonds.
II. **False.** Increasing the red blood cell count does not affect the curve.
III. **True.** Hypocarbia means that the blood is more alkaline, so there is a fall in CO_2 in the blood. Hence, less carboxyhaemoglobin is formed. Moreover, with a fall in carbon dioxide, the curve would shift leftwards to increase the affinity of haemoglobin to oxygen so that haemoglobin binds more tightly to oxygen. This is because with less CO_2 the respiring tissues require less levels of oxygen so not so much oxygen needs to be released by haemoglobin.
IV. **False.** The area marked is at high P_{O2} where oxygen levels are high like the lungs and alveoli. Exercising tissues would have low P_{O2} levels.
V. **True.** With a higher specific metabolic rate, the animal requires more oxygen per unit time. Thus, more oxygen needs to be released to the respiring tissues, so haemoglobin needs to bind less tightly to oxygen, so the affinity of haemoglobin to oxygen should fall and the curve would shift to the right.

Hard Animals

HA 3: I want to pee

Carbonic anhydrase is an enzyme that catalyses the interconversion of H_2CO_3 and $CO_2 + H_2O$ 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

Hard Animals

Answer: **C**

Explanation: We can use the diagram to aid us in analysing the effect of the carbonic anhydrase (CA) inhibitors.

I. **False.** From the diagram, they increase urinary bicarbonate, so pH of urine increases.
II. **True.** From the diagram, they increase urinary Na^+, which pulls free water along with it, hence the urine will contain more Na^+ and water.
III. **False.** From the diagram, they decrease serum bicarbonate, so pH of the blood will decrease, hence worsening the effect of blood acidosis.
IV. **True.** From the diagram, they decrease serum Na^+, so the activity of Na-K pump increases, causing K^+ to be lost from the blood as the body attempts to raise the level of Na^+ in the blood.
V. **True.** The alkaline environment created by these CA inhibitors increases the precipitation of calcium phosphate, forming calcium phosphate stones.

Credits:

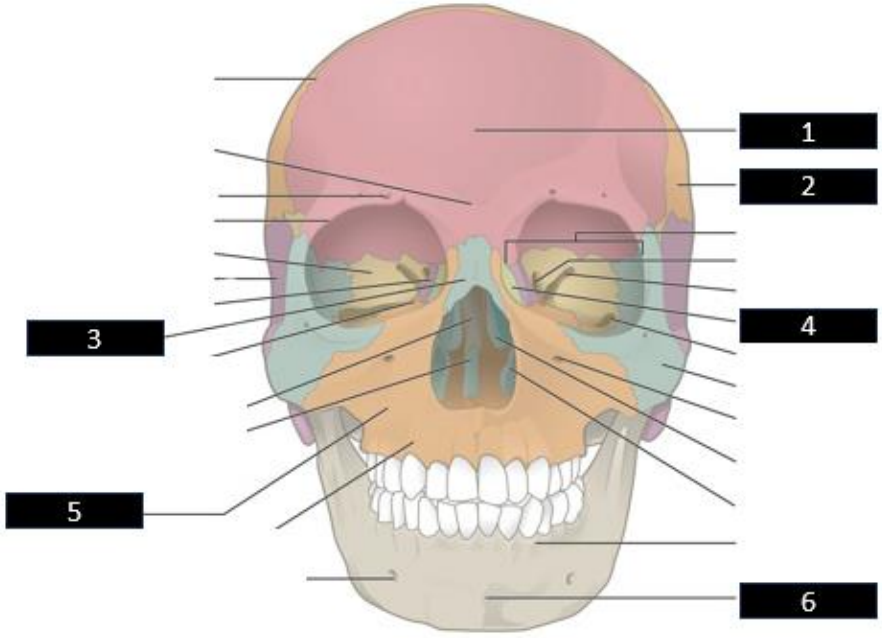
Modified from *Acetazolamide [TUSOM | Pharmwiki]*. PharmWiki. (2018, September 16). https://tmedweb.tulane.edu/pharmwiki/doku.php/acetazolamide

Hard Animals

HA 4: T-Rex Rexsurrection

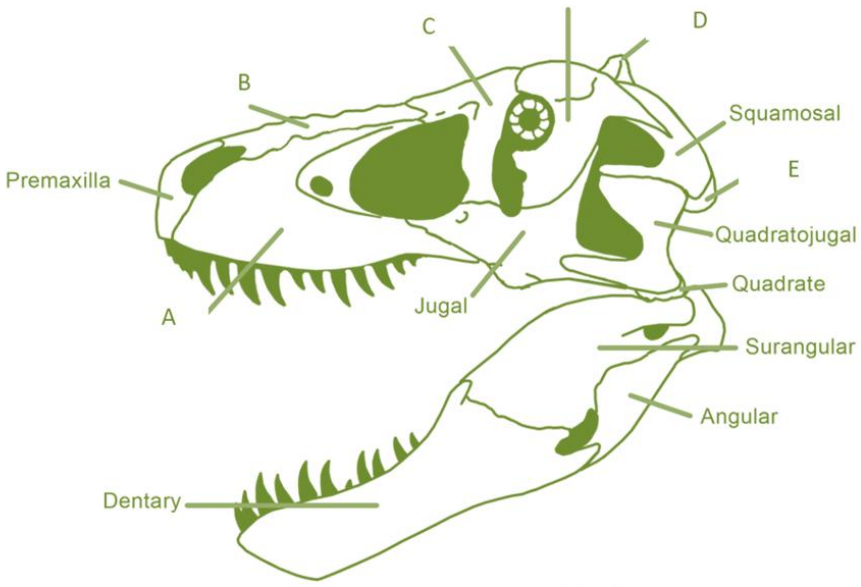
The *Tyrannosaurus Rex* (*T. Rex*) is a theropod that lived in what is now western North America. It lived about 90 to 66 million years ago, at the end of the Late Cretaceous. Despite the fact that our lineage diverged from that leading to the dinosaurs a long time ago, vertebrate homologies do exist, 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).



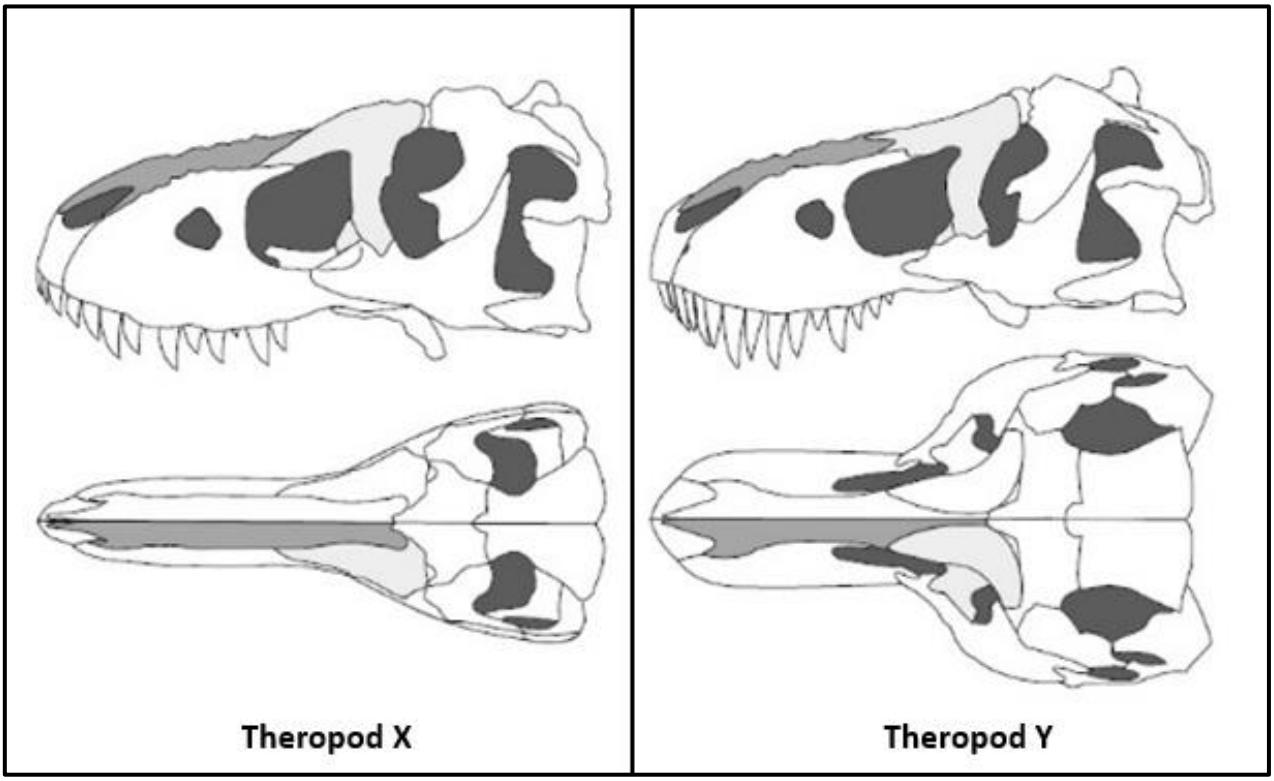
Anterior View

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



Hard Animals

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

Hard Animals

Answer: **C**

Explanation:

I. **False.** Structure 1 is the frontal bone while Structure C is the lacrimal bone. We can tell that they are not homologous as structure 1 does not go down along the orbit, while structure C does.
II. **False.** Structure 2 is the parietal bone while Structure E is the occipital bone. We can tell that they are not homologous because they are in very different positions on the skull.
III. **True.** Structure 3 and Structure B are clearly the nasal bones.
IV. **False.** Structure 6 is the mandible while Structure A is the maxilla. They are clearly not homologous as they are on different sides of the palate.
V. **True.** The right pair of skulls have a larger width and thus greater bite force.

Credits:

Human skull: Modified from OpenStax, L. L. &. (n.d.-b). *Anatomy and physiology I*. The Skull | Anatomy and Physiology I. https://courses.lumenlearning.com/suny-ap1/chapter/the-skull/

T. rex skull: Modified from Hartman, S. (2012). *Scott's Handy-Dandy Guide to Dinosaur Anatomy*. Dr. Scott Hartman's Skeletal Drawing.com. https://www.skeletaldrawing.com/anatomy.

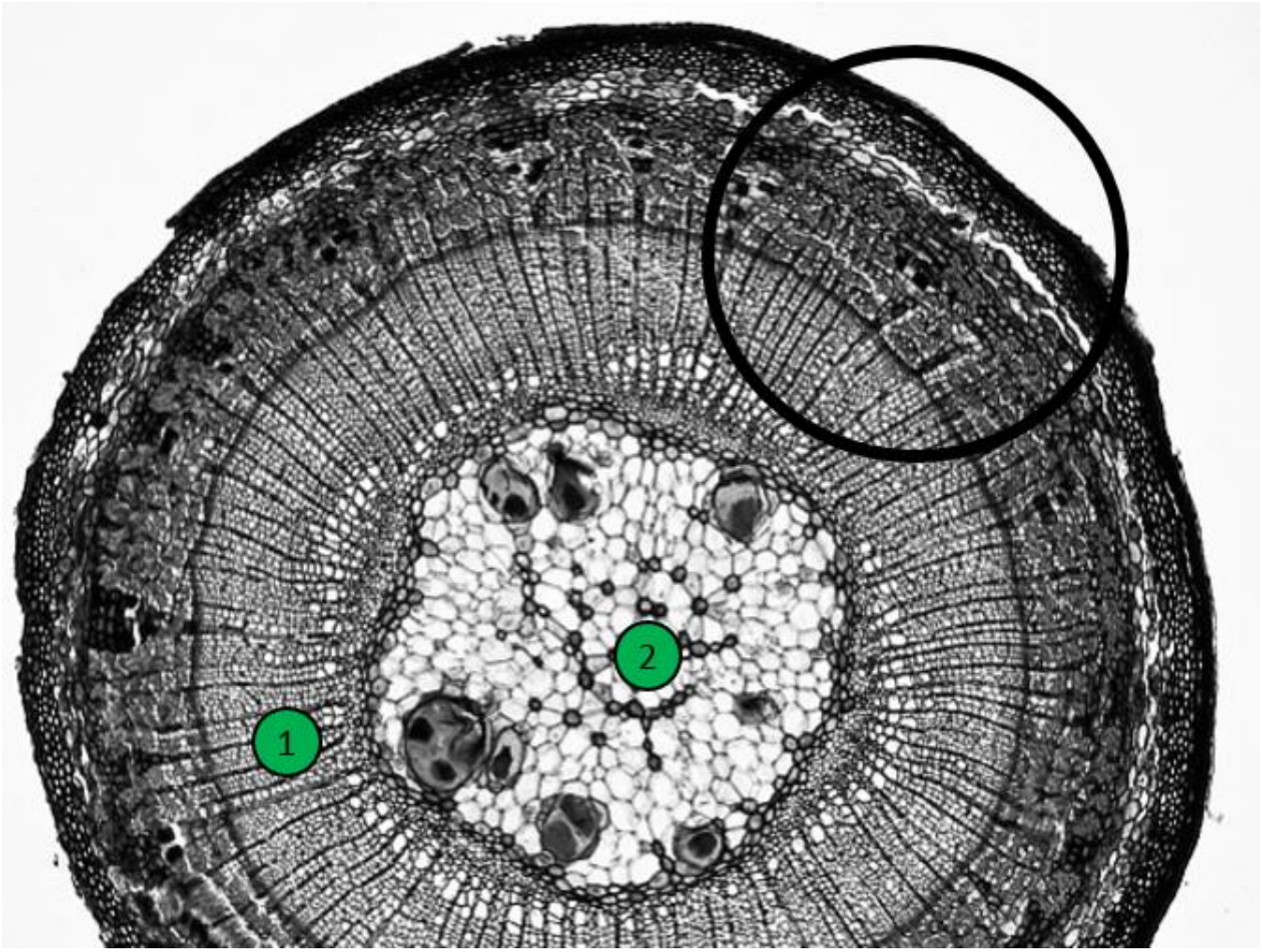
Theropod X and Y: Modified from Hurum, J.H., & Sabath, K. (2003). Giant theropod dinosaurs from Asia and North America: skulls of Tarbosaurus bataar and Tyrannosaurus rex compared. *Acta Palaeontologica Polonica, 48*.

Hard Plants

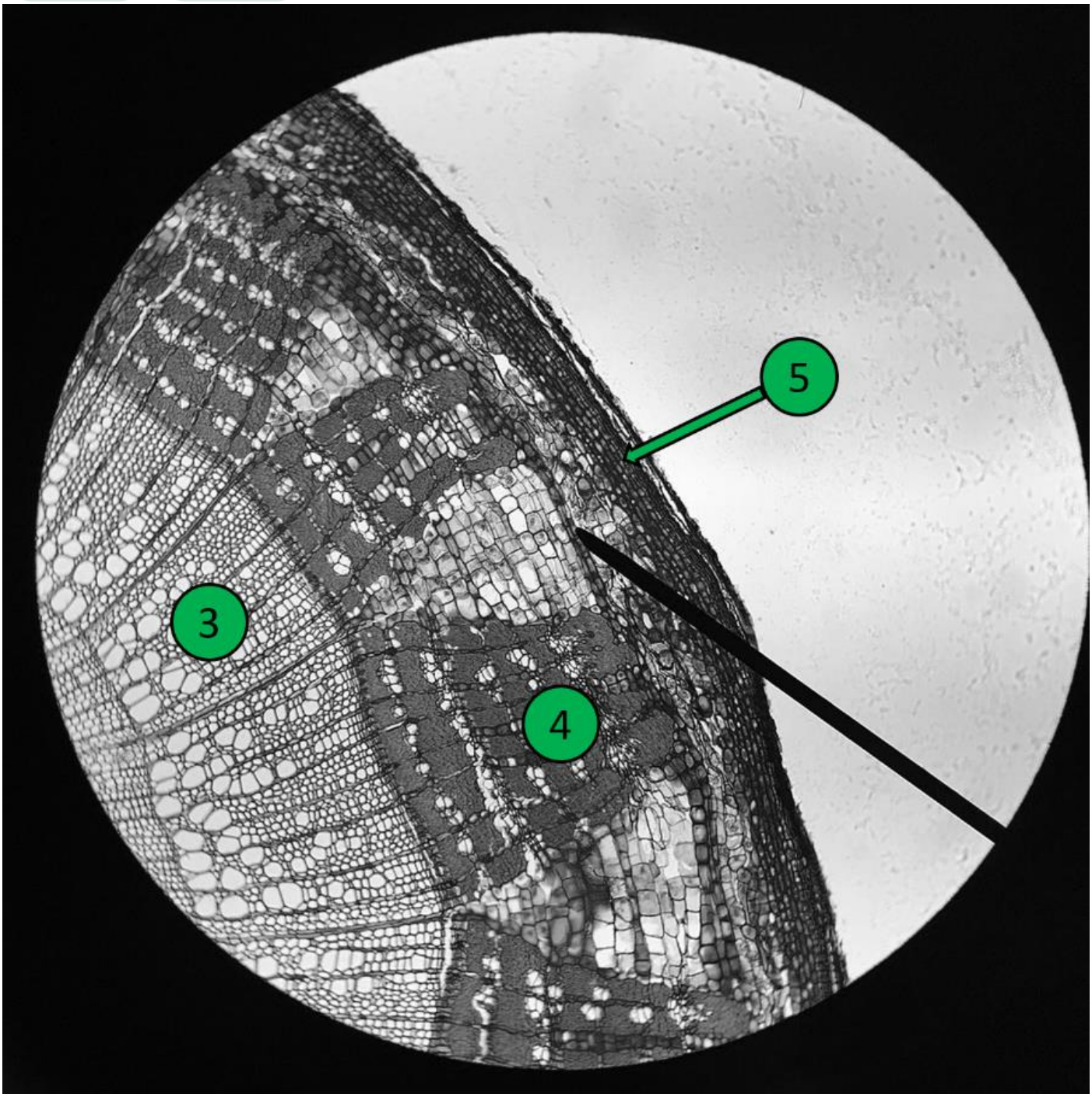
HP 1: Cyber Green

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.



Hard Plants



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

Hard Plants

Answer: **B**

Explanation: The parts that fluoresce contain DNA. Hence, cells that are dead at maturity and have lost their DNA will not fluoresce.

Part 1 is the xylem which are dead at maturity and do not have any DNA. Hence, it will not fluoresce. It appears that this plant is a relatively young plant that is only one year old. Thus, only one xylem ring is seen and there is no distinction between primary and secondary xylem.

Part 2 is the pith which is the ground tissue made of living parenchyma cells. Hence it will fluoresce.

Part 3 is also the xylem. It will not fluoresce.

Part 4 is the phloem which is made of living cells. While the phloem is made of sieve tube elements which lose their nuclei upon maturity, companion cells still retain their DNA, and the sieve tube elements do not lose their mitochondria. Hence, the phloem will still fluoresce.

Part 5 is the phellem, also known as cork, which is made of dead cells. Since this plant is only one year old, the phellem has yet to be sloughed off and it still appears intact together. Hence, it will not fluoresce.

Credits:

Second photomicrograph: Modified from Kje4532. (2016, July 6). *Cork cambium 1.jpg*. Wikipedia. https://commons.wikimedia.org/wiki/File:Cork_cambium_1.jpg#mw-jump-to-license

Hard Plants

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 $P700^*$

Hard Plants

Answer: **A**

Explanation: Under physiological standard state, the only redox reaction which will have a positive E^o value and reduces $Reducin\ (ox)$ is $Reducin\ (ox) + P700^* \rightarrow\ Reducin\ (red) + P700^+$, where $E^o = +0.3V$. This disrupts the normal $Fd(ox) + P700^* \rightarrow Fd(red) + P700^+$ which occurs in the chloroplasts.

In standard state, either $H2O$ or $P700^*$ can reduce $Reducin\ (ox)$ and since photolysis of water occurs earlier in non-cyclic photophosphorylation than oxidation of $P700$, $Reducin\ (ox)$ is reduced by $2H_2O + 4\ Reducin\ (ox) \rightarrow O_2 + 4H^+ + 4\ Reducin\ (red)$. This disrupts the initial transfer of electrons produced by photolysis of water to $P700^+$.

Hard Plants

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.

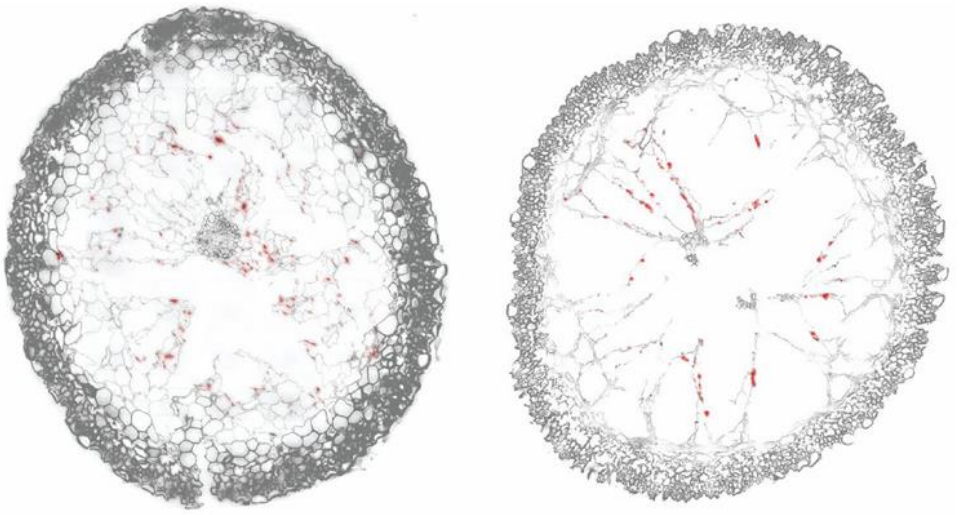


Figure 1

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.

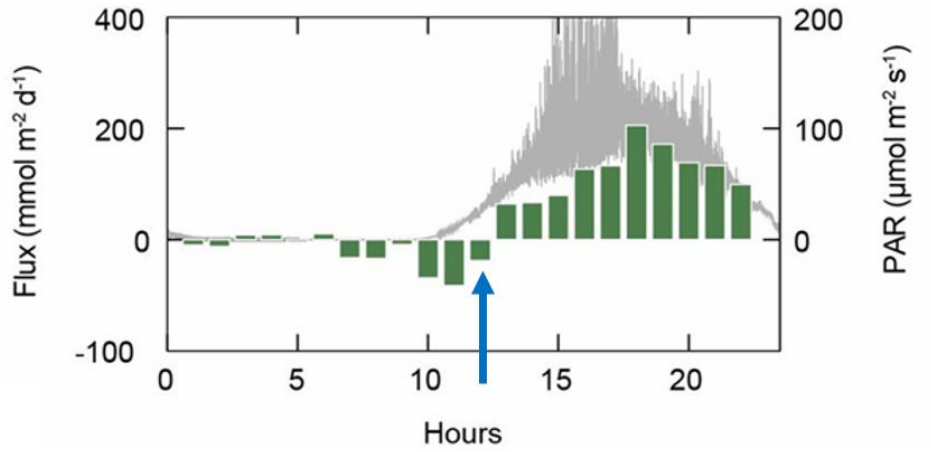


Figure 2

Hard Plants

Next, Jacob conducted an $^{15}N_2$-labelling experiment with the following set-up in Germany where the seagrass meadow and CNN in its roots are incubated together in different months. $^{15}N_2$ was added to the water and the $^{15}N_2$ concentration in the water was measured after 1 week for the set-ups in each month. The results are shown below.

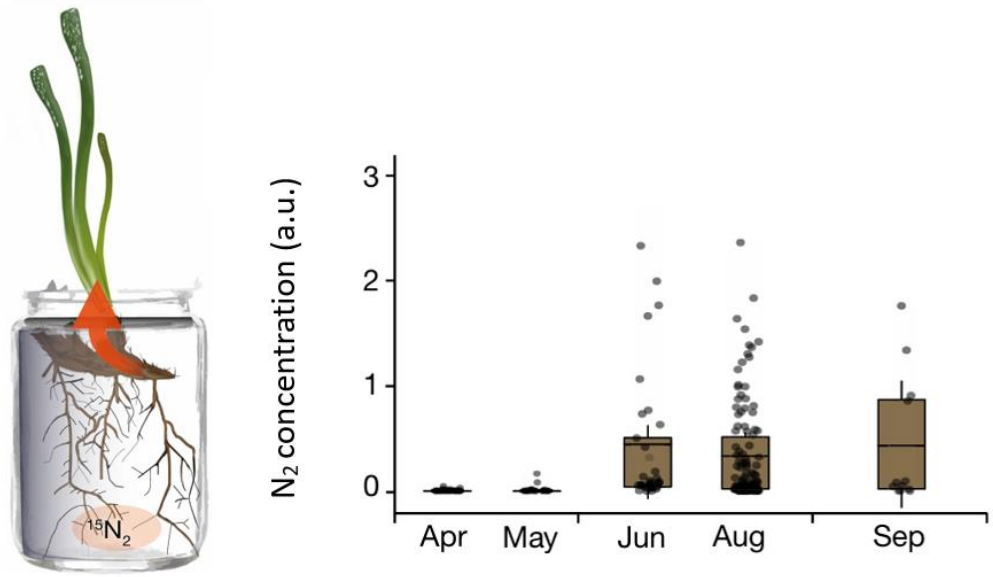


Figure 3

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 CO_2 fixed per day.
V.	Some of the $^{15}N_2$ 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

Hard Plants

Answer: **D**

Explanation: Be careful as the question requires false and not true statements.

I. **True.** From Figure 1 it is clear that the CCN cells in red are localised to the cortex and not the rhizoplane.

II. **True.** Oxygen flux is moving from negative to positive so rate of photosynthesis is starting to go from less than that of respiration to more than that of respiration. Hence this is most likely the time when light starts to appear i.e. dawn. It is also when the PAR starts to increase.

III. **False.** Oxygen flux is negative but is less negative than 2 hours before, indicating that photosynthesis should have started to occur but at low rates, which is why the oxygen flux became less negative but not positive.

IV. **False.** The NPP can be calculated by the difference between the gross primary productivity which is the amount of carbon fixed and the amount of carbon released by respiration. We take the sum of all the green bars and divide it by 24h. This is because the units of the y-axis indicates in days, which means that we need to divide each bar by 24h as each bar only represents 1h. If we estimate the tallest positive bar to be 200, while the intermediate is 100 and the smaller ones are 50, and the negative bars to be approximately -25 to -50 (take note the scale is different for the negative y-axis!), we get approximately 50 mmol m^{-2} of CO_2 fixed per day.

V. **False.** Sucrose does not contain nitrogen.

Credits:

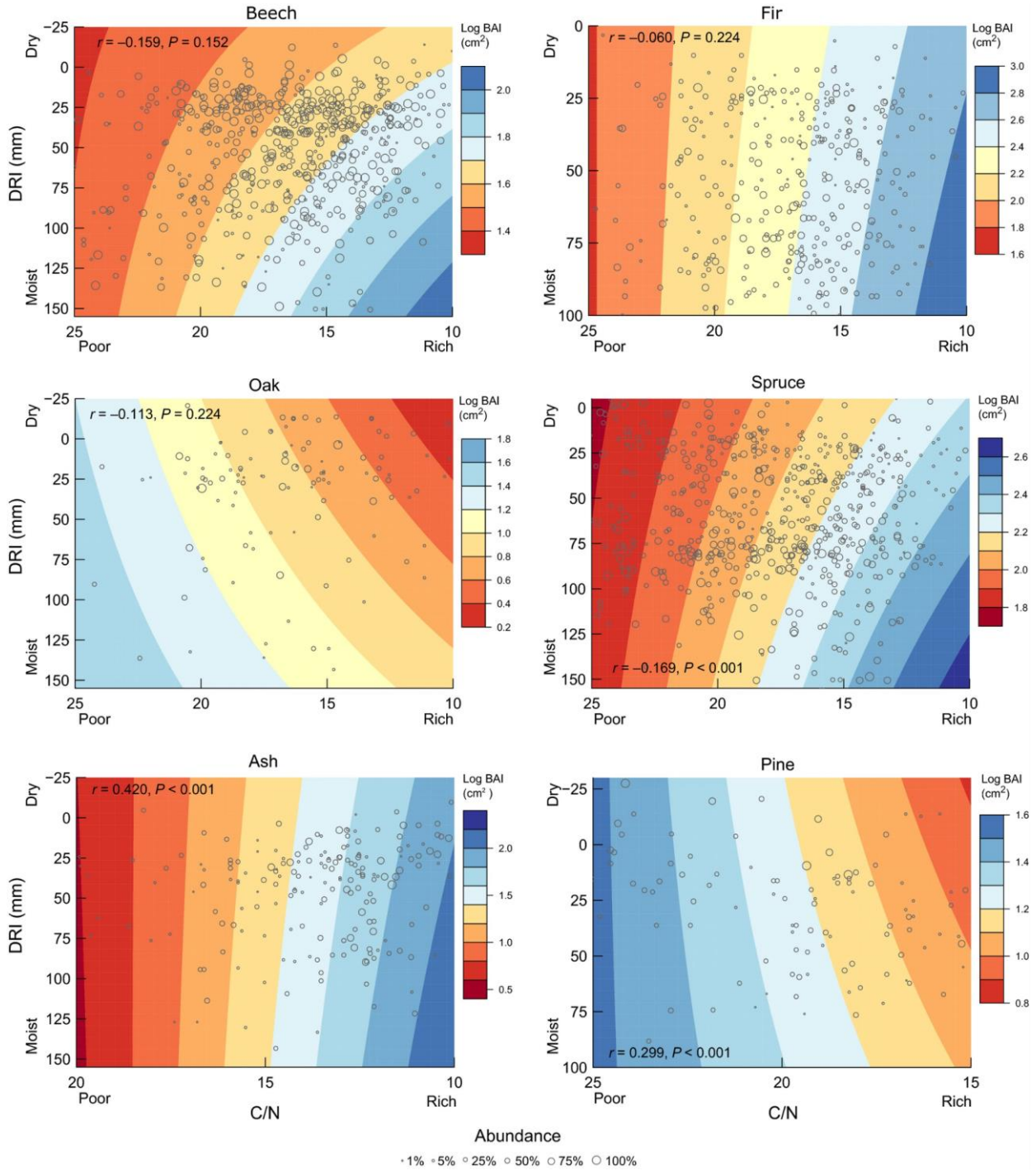
Modified from Mohr, W., Lehnen, N., Ahmerkamp, S., Marchant, H. K., Graf, J. S., Tschitschko, B., Yilmaz, P., Littmann, S., Gruber-Vodicka, H., Leisch, N., Weber, M., Lott, C., Schubert, C. J., Milucka, J., & Kuypers, M. M. (2021). Terrestrial-type nitrogen-fixing symbiosis between seagrass and a marine bacterium. *Nature*, *600*(7887), 105–109. https://doi.org/10.1038/s41586-021-04063-4

Hard Plants

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.



Hard Plants

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

Hard Plants

Answer: **C**

Explanation:

I. **True.** At low DRI and high C/N, both beech and oak show a BAI of around 1.4 cm^2.
II. **False.** At C/N of 10, oak and pine will have lower growth rates than the other four species.
III. **False.** We cannot tell the effects of having a C/N ratio of 1 from the graph.
IV. **True.** Desiccated soil decreases DRI which, upon visual inspection of the graph, shows a decrease in BAI in all six species.

Credits:

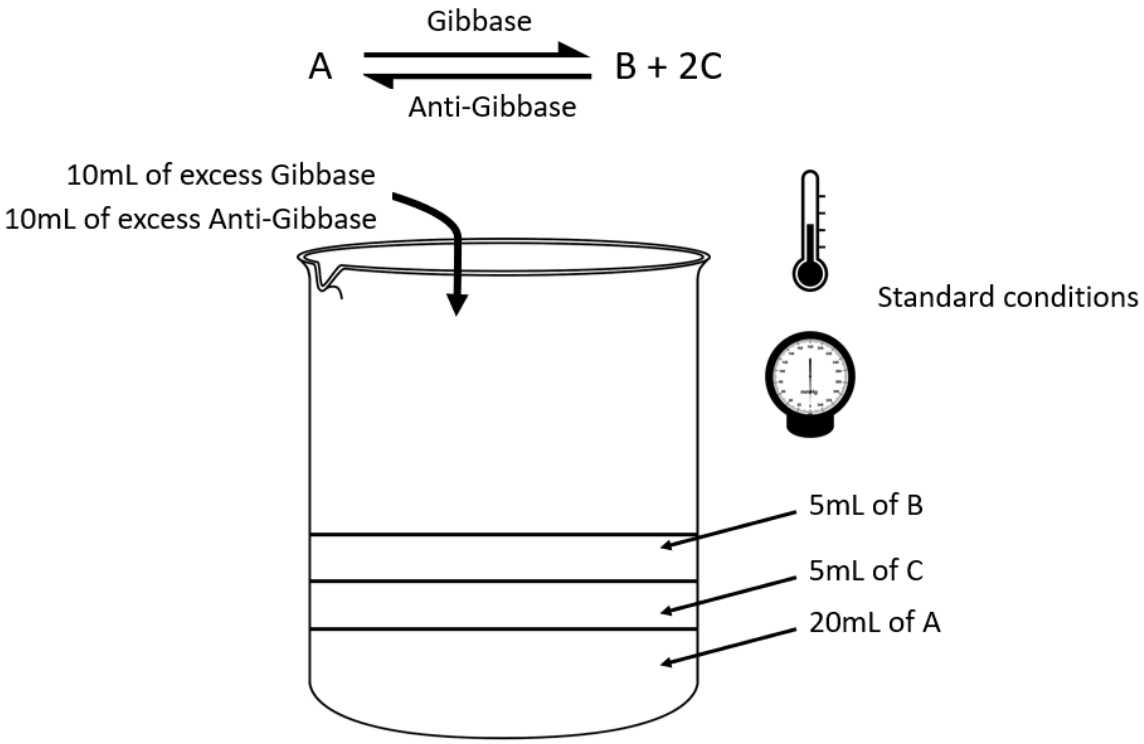
Lévesque, M., Walthert, L., & Weber, P. (2016). Soil nutrients influence growth response of temperate tree species to drought. *Journal of Ecology*, *104*(2), 377–387. https://doi.org/10.1111/1365-2745.12519

Hard Cell Biology

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 ($\Delta G°$) indicates the thermodynamic favorability of a physical or chemical process. When $\Delta G° < 0$, the process is thermodynamically favoured, while when $\Delta G° > 0$, 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 ($\Delta G°$) by gibbase (298K)?

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

Hard Cell Biology

Answer: **D**

Explanation: This can be solved using the equation:

$$\Delta G^o = -RT \ln K$$

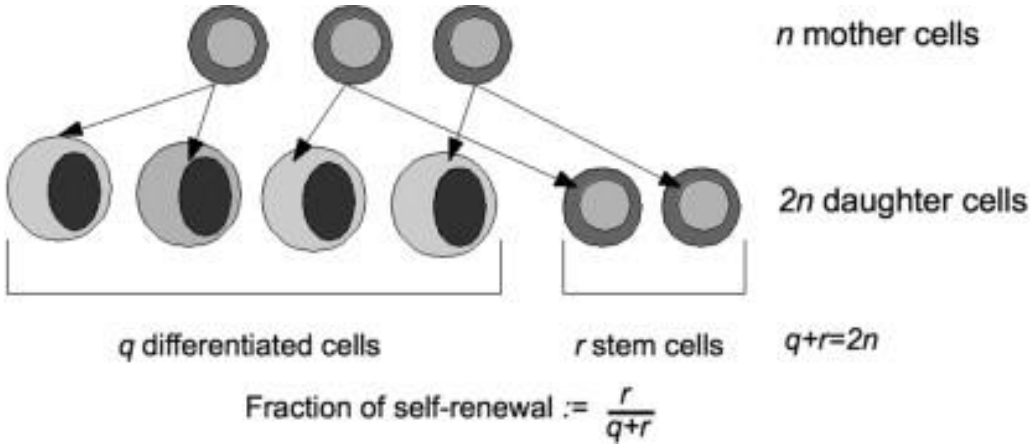
$$\Delta G^o = -8.314\ (273.15) \ln \left(\frac{[B][C]^2}{[A]} \right)$$

$$\Delta G^o = -8.314\ (298) \ln \left[\frac{\left(\frac{0.029}{50 \times 10^{-3}} \right) \left(\frac{0.00273}{50 \times 10^{-3}} \right)^2}{\frac{0.0021}{50 \times 10^{-3}}} \right] = +7.90\ kJ\ mol^{-1}$$

Hard Cell Biology

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.

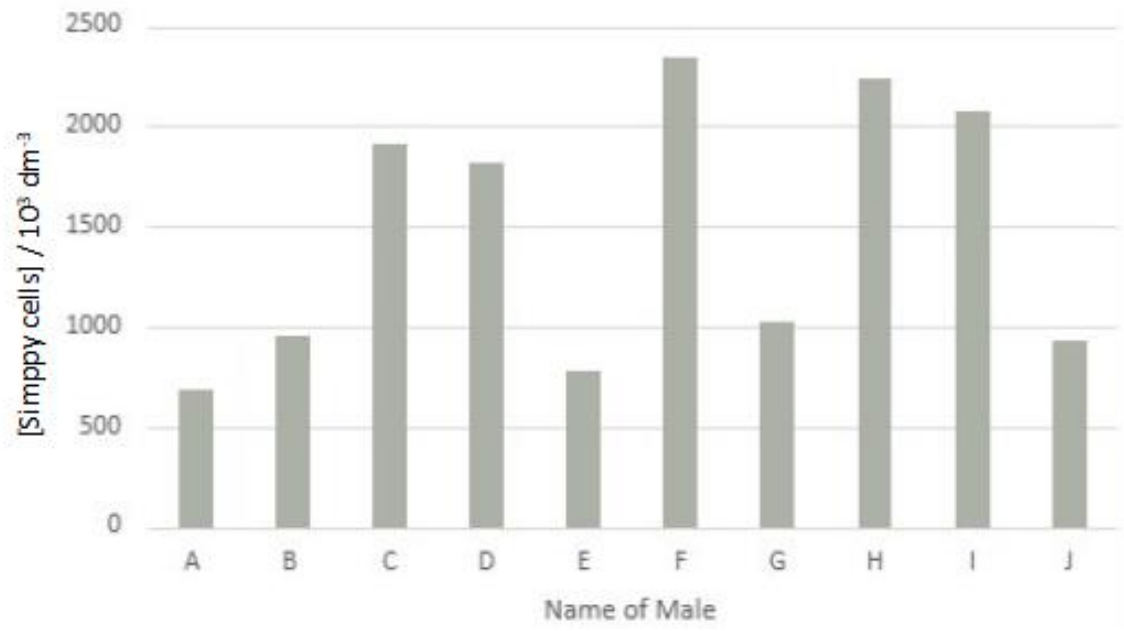


Jerome is investigating the differentiation rate of simponisa cells in giant male rats. Simponsia cells differentiate to form only simppy cells which regulate the levels of testosterone in the bloodstream. This cell cannot be produced by any progenitor cells other than simponisa cells. Thus, simponisa 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.

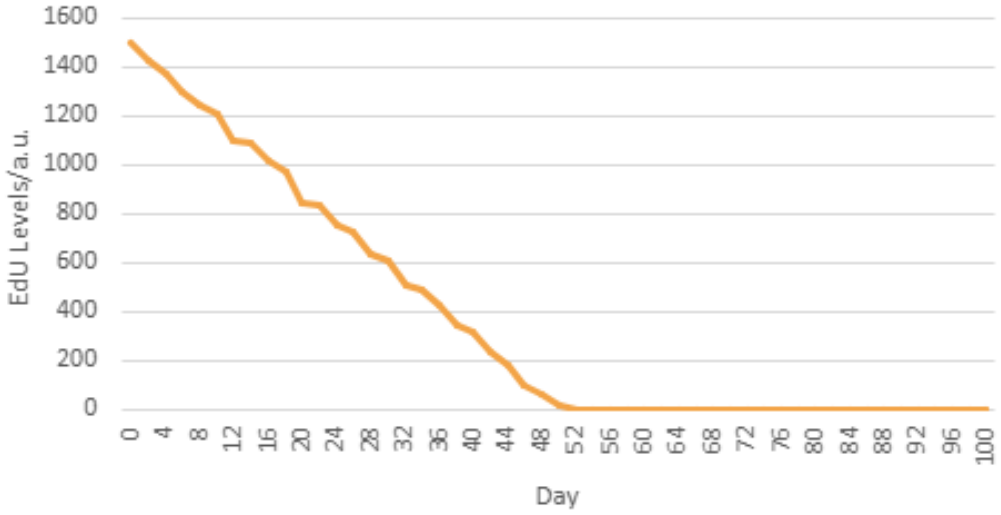
Jerome takes a blood sample from ten giant male rats to detect the levels of simppy cells in their bloodstream. These giant male rats have a total blood volume of five litres on average. Unfortunately, he realised later that while the rest of them are normal, five of them suffer from clingee, which cause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

Hard | Cell Biology

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

Hard | Cell Biology

Answer: **C**

Explanation: From the bar chart, the normal rats have the higher concentrations of simpee cells (rats C, D, F, H and I) because the other rats suffering from clingee have their immune system killing the simpee cells off which results in lower concentrations inside their bloodstream. For the 5 healthy rats, we can estimate 2 million cells are present per cubic decimetre (equivalent to a litre).

In the preamble, we are told the rats have 5 litres of blood in total, so the total count is around 10 million simpee cells per healthy rat. Based on the line graph, all the simponisa cells are replaced in 50 days. Also, from the first diagram and the question context (the fraction of self-renewal being 0.5), we can infer that the simponisa cell numbers stay constant and the rate of production of simppy cells matches their rate of clearance because their levels also stay constant. The rate of clearance is $\frac{10000000}{50} = 200000$ per day, which means the rate of production is that many divisions per day too.

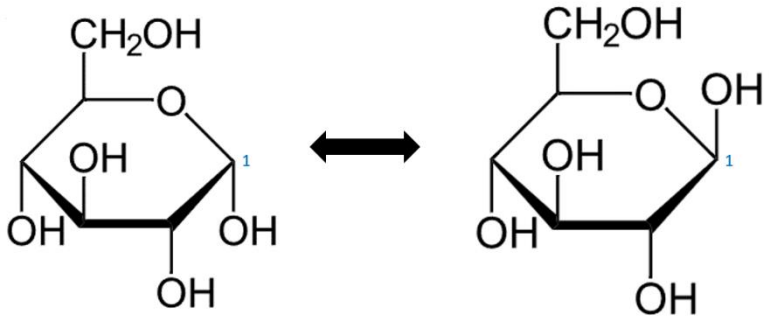
Credits:

Fraction of self-renewal diagram: Stiehl, T., & Marciniak-Czochra, A. (2011). Characterization of stem cells using mathematical models of multistage cell lineages. *Mathematical and Computer Modelling*, *53*(7–8), 1505–1517. https://doi.org/10.1016/j.mcm.2010.03.057

Hard Cell Biology

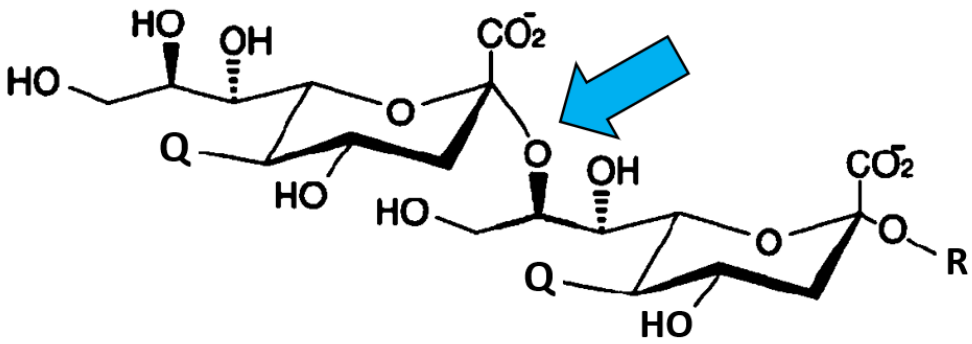
HC 3: Alpha and Beta

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



α-glucose β-glucose

The diagram below shows a molecule.



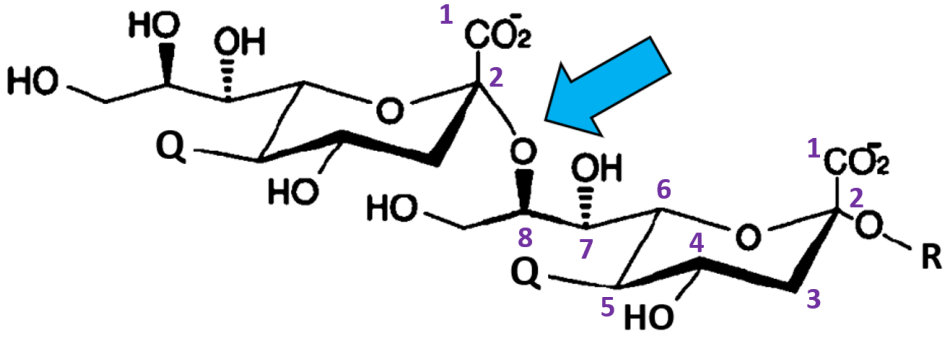
By analysing the stereochemistry of the molecule above, what glycosidic bond is indicated by the blue arrow?

A. β(1,7)
B. α(2,2)
C. β(2,7)
D. α(2,8)

Hard Genetics

Answer: **D**

Explanation: By counting and labelling the carbon atoms in the molecule, we get:



It is clear that the glycosidic bond is between C2 and C8. The orientation of the two monomers are in the same direction, which suggests this to be an alpha bond. Hence, it is an α(2,8) glycosidic bond.

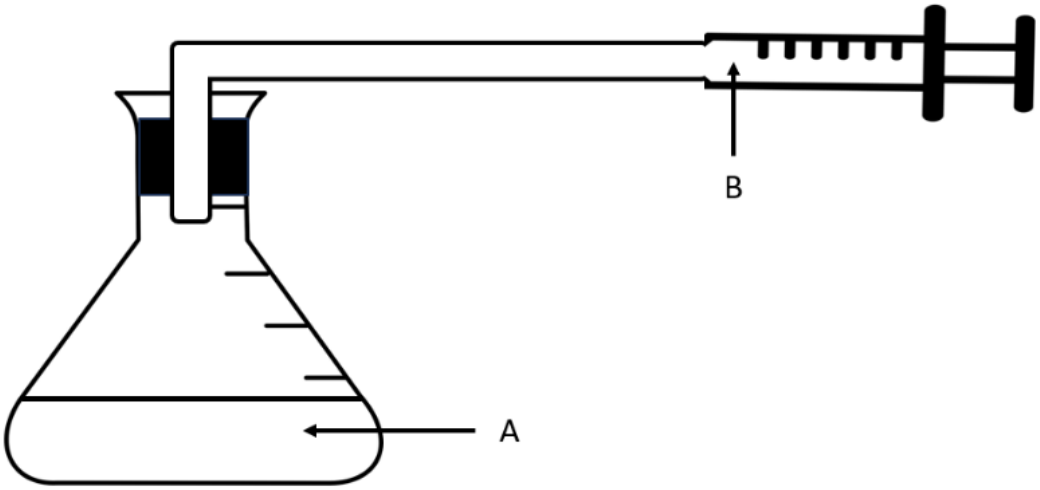
Credits:

Modified from Cohen, M., & Varki, A. (2010). The sialome--far more than the sum of its parts. *Omics : a journal of integrative biology*, *14*(4), 455–464. https://doi.org/10.1089/omi.2009.0148

Hard Genetics

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

Hard Genetics

Answer: **A**

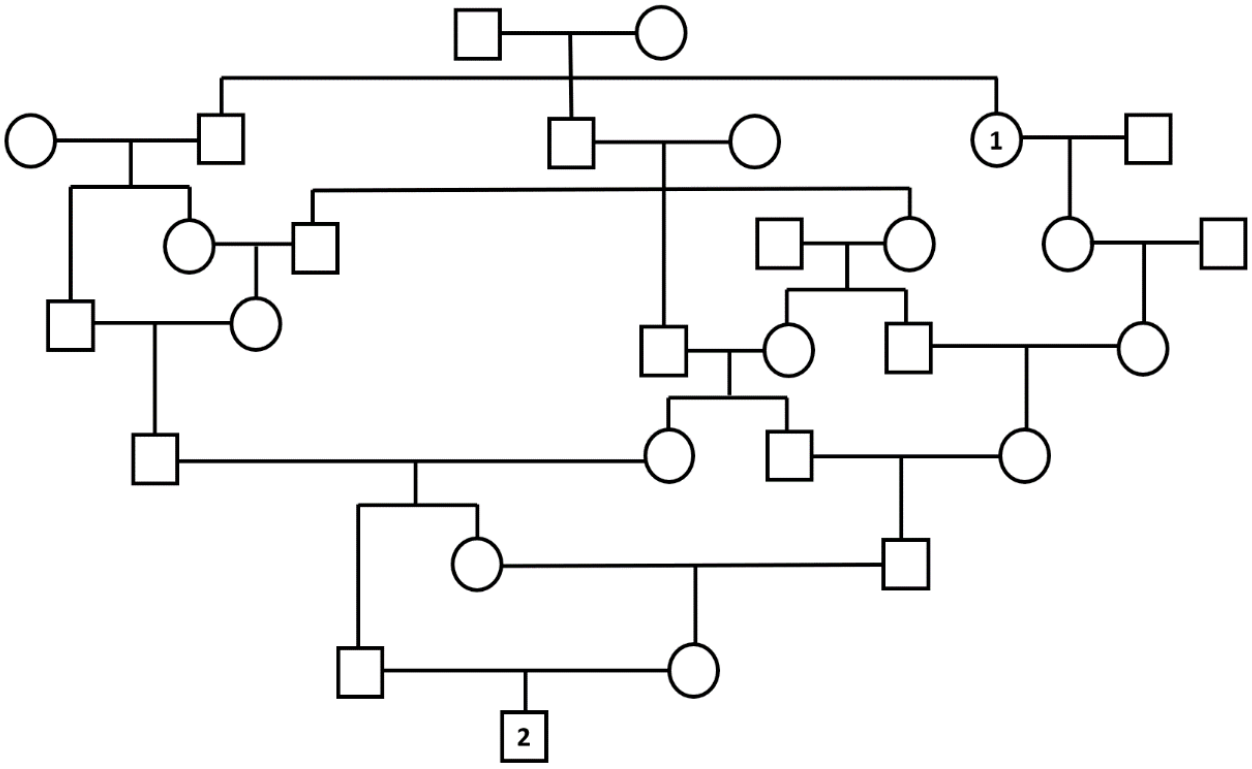
Explanation: The total radioactivity should remain at 6 in each flask. Under normal aerobic respiration conditions, the radioactive glucose is converted to pyruvate via glycolysis and no carbon dioxide is released. Next, each mole of pyruvate releases one mole of CO_2 during the link reaction, hence 2 moles of carbon dioxide are produced. Subsequently, all four moles of carbon dioxide are released in the two rounds of the TCA cycle. Two moles of CO_2 are released per round for each mole of Acetyl-CoA. Hence, all the radioactive carbon in the glucose is released as radioactive carbon dioxide, so the gaseous products will have radioactivity of 6 Bq and the aqueous products will be 0 Bq.

Since X inhibits cytochrome c in the electron transport chain, the electron transport chain will be unable to accept electrons from NADH and $FADH_2$ that come from glycolysis, the link reaction, and the TCA cycle. Thus, they remain reduced and the link reaction and TCA cycle are stalled. Glycolysis can still proceed but under anaerobic respiration. One mole of glucose is converted to pyruvate which is converted to 2 moles of CO_2 and acetaldehyde. This subsequent conversion of acetaldehyde to ethanol regenerates NAD^+ to continue to be used for anaerobic respiration. Hence, the gaseous products will have a radioactivity of 2 Bq, and that of the aqueous products will be 4 Bq.

Hard Genetics

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?

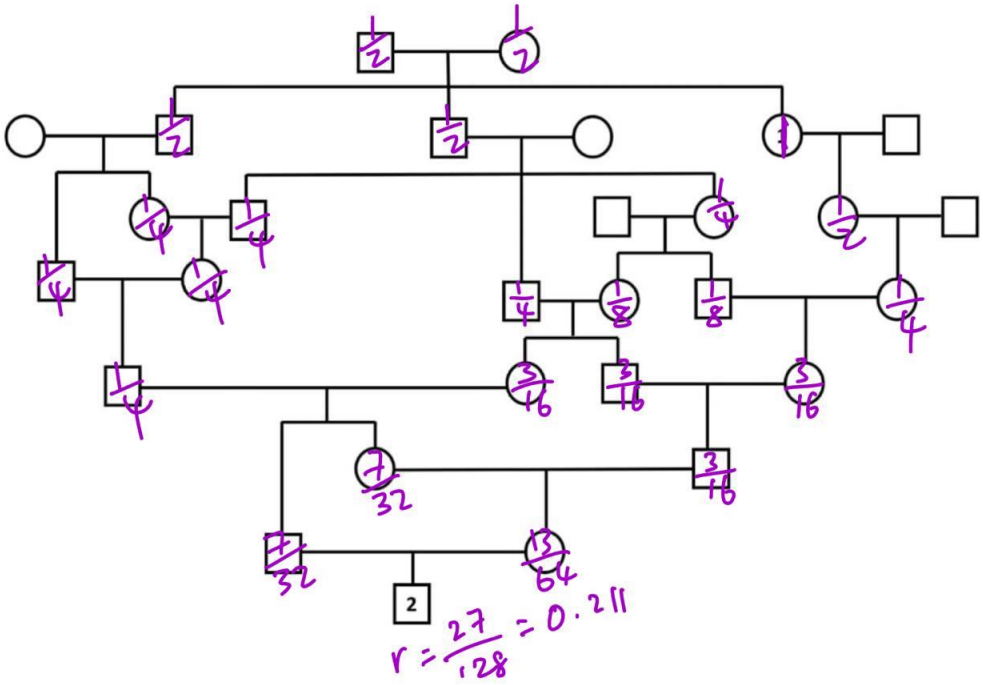
A. 0.0156
B. 0.0178
C. 0.211
D. 0.227

Hard Genetics

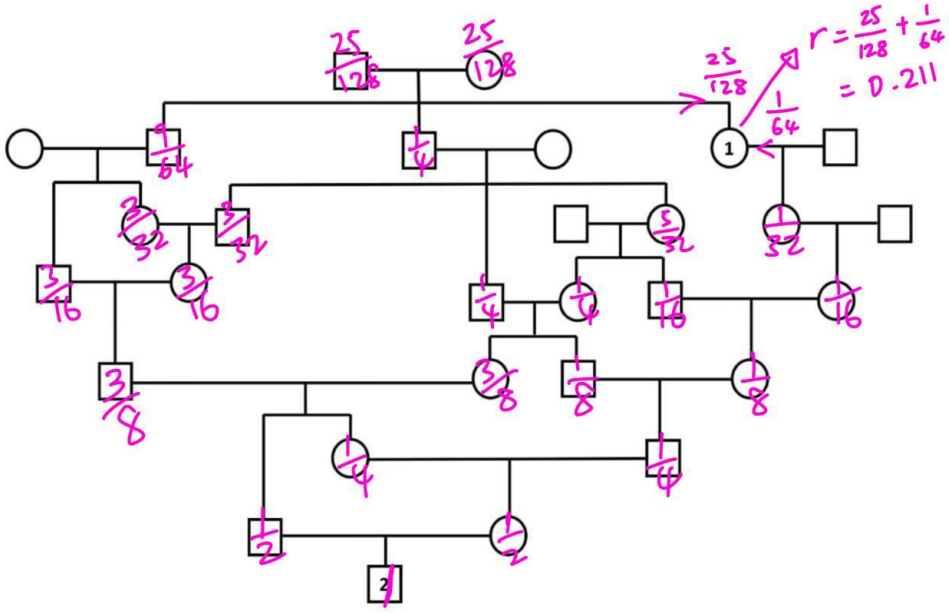
Answer: **C**

Explanation: The idea of coefficient of relatedness is the proportion of your genome that you share with the person of interest. For example, the coefficient of relatedness between you and your mother is ½ because you have one of each pair of her chromosomes.

We can assign the coefficient of 1 to Individual 1 and consider the route that leads to Individual 2:



Alternatively, we can assign the coefficient of 1 to Individual 2 and by considering each route that connects the genes between both individuals, we can get:



Hard Genetics

Participants may realise that assigning Individual 1 with the coefficient of 1 is the simpler method.

With either method, we get the coefficient of relatedness to be 0.211.

This highlights the problems of inbreeding. While Individual 1 and 2 are 5 generations away and should theoretically have a coefficient of relatedness of $\left(\frac{1}{2}\right)^5 = \frac{1}{32} = 0.03125$, they have a true coefficient of relatedness of nearly 7 times the theoretical value due to inbreeding! This can cause pronounced homozygosity and recessive diseases may become more common in the family.

Note: Participants were provided with a link during the contest to access an editable version of the pedigree.

Hard Genetics

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).

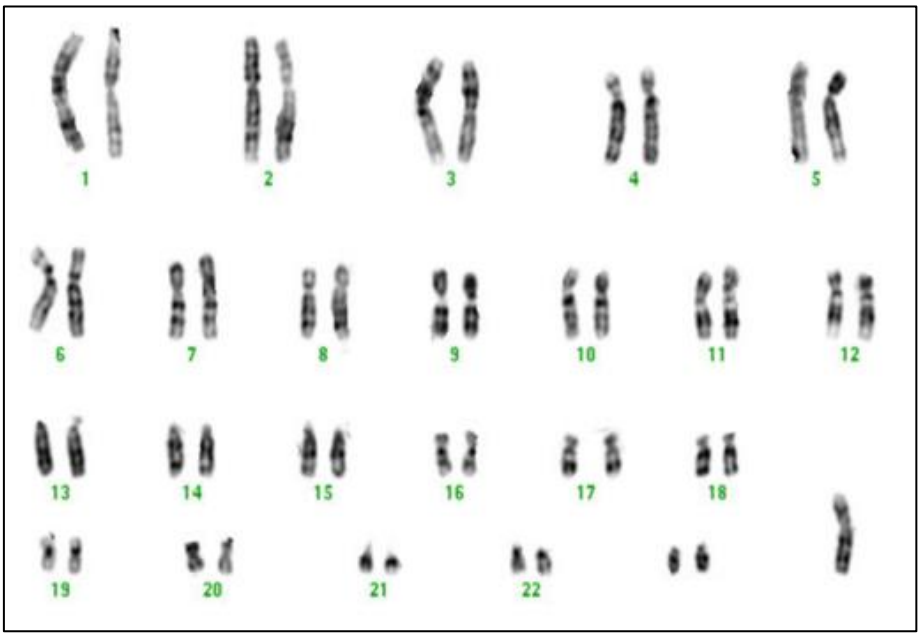


Figure 1: Karyotype of Individual A

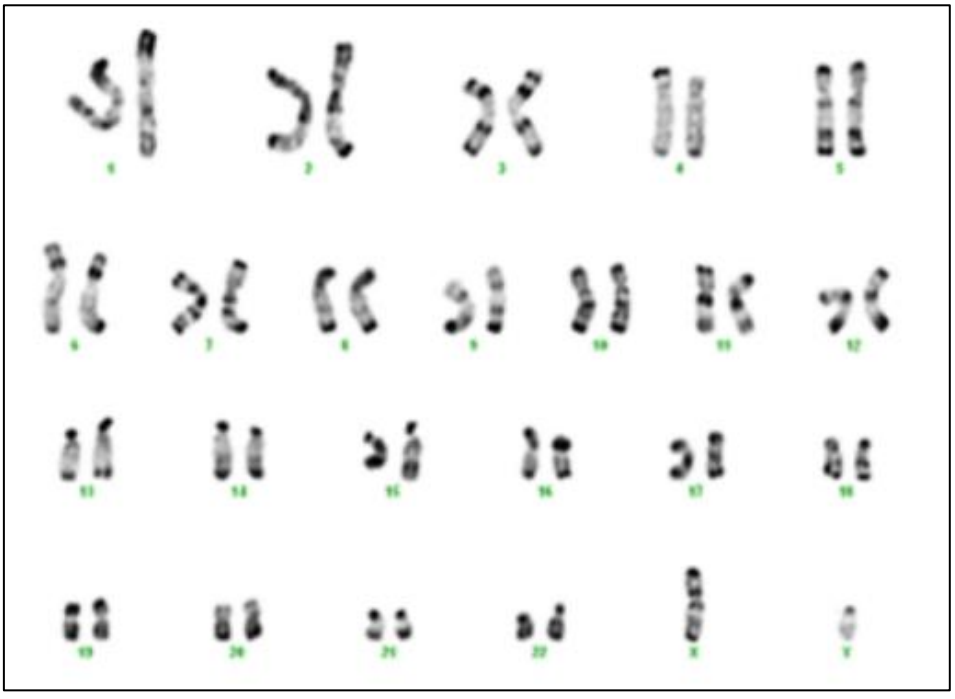


Figure 2: Karyotype of Individual B

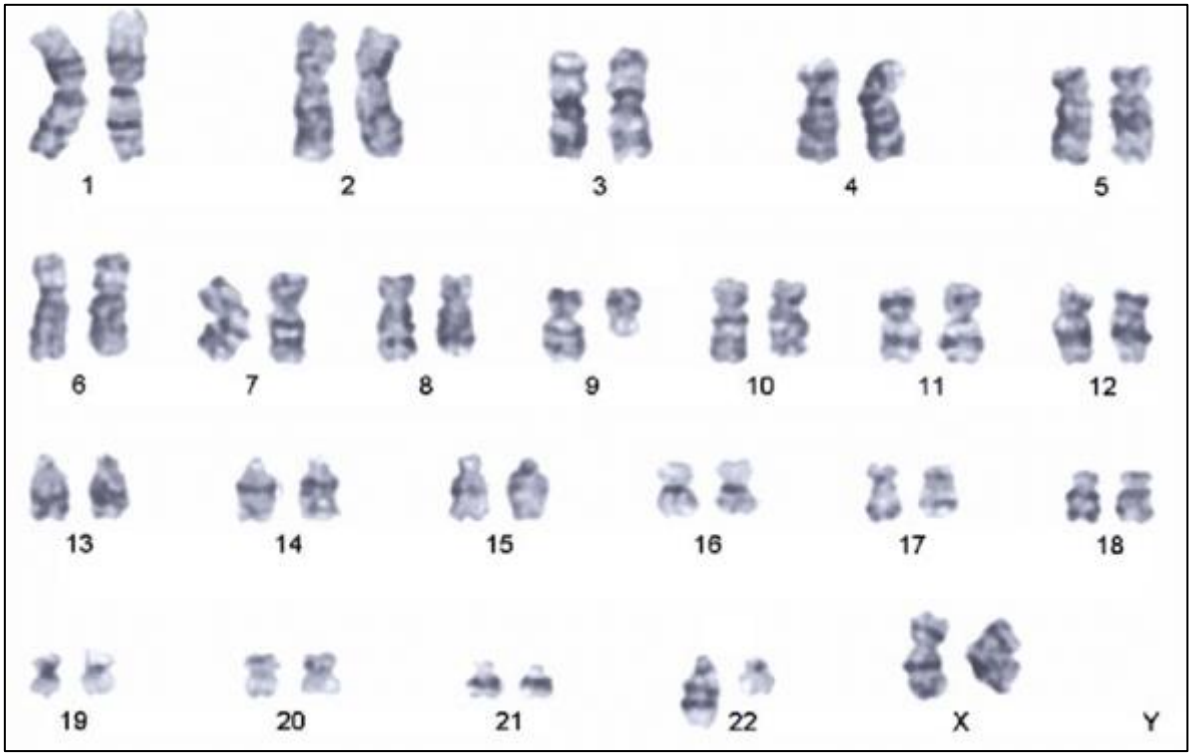


Figure 3: Karyotype of Individual C

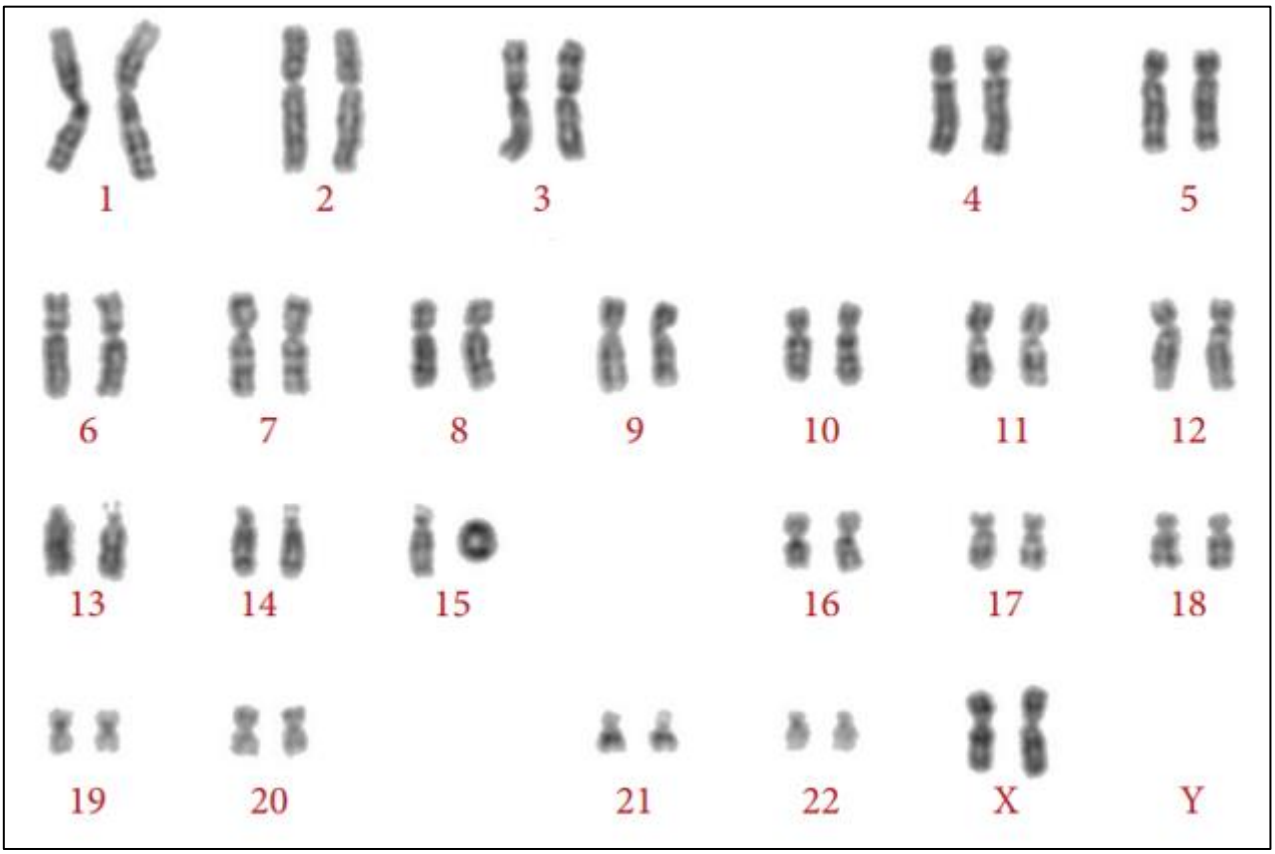


Figure 4: Karyotype of Individual D

Hard Genetics

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

Hard Genetics

Answer: **C**

Explanation: Individual A has one X chromosome and two Y chromosomes (as the Y chromosome is smaller). Thus, he has XYY syndrome which is Jacob's syndrome. Individual B has a partial deletion on the p arm of chromosome 4 (4p) and thus has Wolf–Hirschhorn syndrome. Individual C has a Philadelphia translocation with a reciprocal translocation between chromosomes 9 and 22. Individual D has a ring chromosome 15 which occurs due to the fusing of the p and q arms of the chromosome.

I. **True.** Individual A is likely sterile and can thus ejaculate semen but there will be no sperm.
II. **False.** Non-disjunction during meiosis I cannot have occurred. The non-disjunction must have occurred in the father. If non-disjunction had occurred in the father, the gamete will be XY, which would fuse with a normal ovum to give an offspring with genotype XXY. Hence, non-disjunction must have occurred during meiosis II so that the Y chromosome is not separated into separate gametes and the gamete will contain two Y chromosomes.
III. **False.** It is a deletion.
IV. **True.** The Philadelphia translocation fuses the *BCR* and *ABL* genes to form the *BCR-ABL1* oncogene. The coded tyrosine kinase protein is constitutively active and thus there will be uncontrolled cell division.
V. **True.** The deletion at the ends of the p and q arms allow the ends to fuse to form a ring chromosome.

Credits:

Figure 1: Modified from El-Dahtory, F., & Elsheikha, H. M. (2009). Male infertility related to an aberrant karyotype, 47,XYY: four case reports. *Cases journal*, *2*(1), 28. https://doi.org/10.1186/1757-1626-2-28

Figure 2: Modified from Rjiba, K., Ayech, H., Kraiem, O., Slimani, W., Jelloul, A., Ben Hadj Hmida, I., Mahdhaoui, N., Saad, A., & Mougou-Zerelli, S. (2021). Disorders of sex development in Wolf-Hirschhorn syndrome: a genotype-phenotype correlation and MSX1 as candidate gene. *Molecular cytogenetics*, *14*(1), 12. https://doi.org/10.1186/s13039-021-00531-8

Figure 3: Modified from Masuko, M., Furukawa, T., Abe, T., Wada, R., Maruyama, S., Kitajima, T., Shibasaki, Y., Toba, K., Okada, M., & Aizawa, Y. (2009). A chronic myeloid leukemia patient with atypical karyotype and BCR-ABL e13a3 transcript caused by complex chromosome rearrangement. *International journal of hematology*, *90*(2), 230–234. https://doi.org/10.1007/s12185-009-0368-4

Figure 4: Modified from Britto, I. S., Regina Silva Herbest, S., Tedesco, G. D., Drummond, C. L., Bussamra, L. C., Araujo Júnior, E., Ruano, R., Ruano, S. H., & Aldrighi, J. M. (2014). Prenatal diagnosis of a fetus with

ring chromosomal 15 by two- and three-dimensional ultrasonography. *Case reports in obstetrics and gynecology*, *2014*, 495702. https://doi.org/10.1155/2014/495702

Hard Genetics

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}

Hard Genetics

Answer: **B**

Explanation: The allele frequencies can be calculated as we know that $p + q = 1$.

$$2pq = \frac{296478}{1000000}$$

$$p + q = 1 \Rightarrow q = 1 - p$$

$$2p(1 - p) = \frac{296478}{1000000}$$

$$2p^2 - 2p + \frac{296478}{1000000} = 0$$

$$p = 0.819 \mid q = 0.181 \ (since\ p > q)$$

Using the equation for selection in the presence of mutation, we get:

$$s = \frac{\mu}{q^2}$$

$$s = \frac{3 \times 10^{-8}}{(0.181)^2} = 9.157229633 \times 10^{-7} = 9.16 \times 10^{-7}$$

While you could have considered the effect of the mutation on the frequency of the q allele, the mutation rate is so low that its effect on the frequency is effectively negligible. We can see this by calculation:

$$s = \frac{3 \times 10^{-8}}{(0.181 + 0.819 \times 3 \times 10^{-8})^2} = 9.157227147 \times 10^{-7}$$

This gives you the exact same answer up to the 5th decimal place!

Hard Genetics

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: $\boldsymbol{V_P = V_G + V_E}$

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 Genetics

Find V_G of population **S** for tail length.

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

Hard Genetics

Answer: **D**

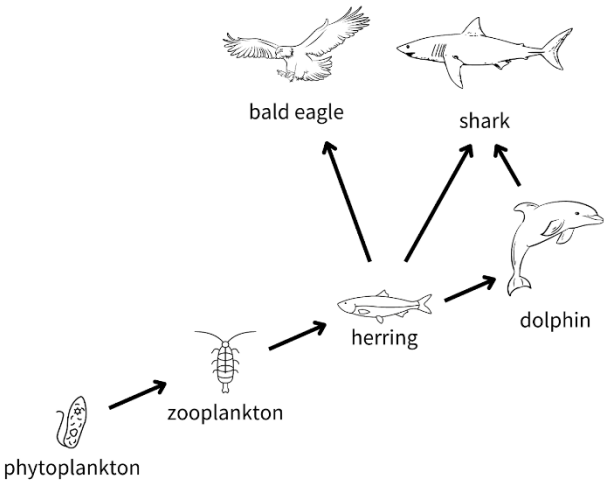
Explanation: Since samples of S were selected from adults and not newborns, the environmental factors were not constant between the two populations. For there to be similar environmental factors, newborns of S would have to be grown in the same environmental setting as newborns of T (e.g. in a controlled laboratory setting). Since this is not the case, V_E of the two populations are not equal.

If they were equal, $V_E = V_P$ of population T as the population is genetically homogeneous (from inbreeding). Hence, V_G of population S can be found from $V_{P(S)} - V_E$.

Hard Ecology

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. A bloom of phytoplankton will increase the average lead concentration of species up the food chain.
B. Dolphins have a lower tissue concentration of lead than bald eagles as biodilution of lead occurs in the seawater.
C. Species of higher trophic levels exhibit increasingly efficient excretion of metals.
D. 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.

Hard Ecology

Answer: **C**

Explanation:

A. **False.** Algal blooms decrease the average lead concentration of species up the food chain as less lead is taken in per individual phytoplankton. Going up the food chain, predators consume the same number of individuals, hence the intake of lead is decreased in an algal bloom scenario.
B. **False.** We cannot be sure why dolphins have a lower lead concentration than eagles. It cannot be attributed to biodilution because both dolphins and eagles have the same trophic level.
C. **Most likely true.** The lead concentrations provided decrease up the food web, which suggests that there is some mechanism in species higher in trophic level that decreases the lead concentration of the individual, such as excretion.
D. **False.** Regardless of the number of calcium-binding sites, the concentration of lead in an individual can increase indefinitely.

Hard Ecology

HE 2: Impostor

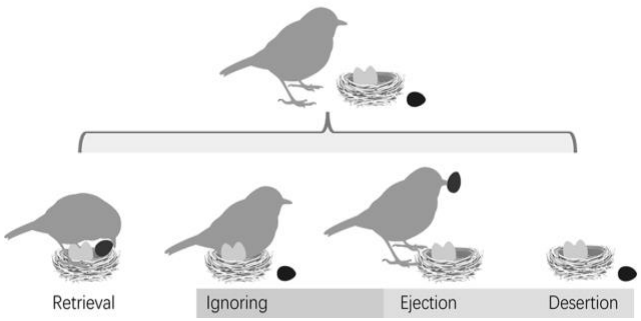
Brood parasites are birds that lay eggs in other species' nests for the allospecific host to care for their young. Parasitic eggs may look extremely similar to host eggs.

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.



Hard Ecology

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

Hard Ecology

Answer: **B**

Explanation:

I. **False.** Egg retrieval is a fixed action pattern that cannot be interrupted until completion.

II. **True.** This is shown by the percentage of model eggs accepted by shamas (13%) than magpie-robins (0%), indicating that the ability of shamas to differentiate between egg and non-egg objects (the stimulus of egg retrieval) is weaker than magpie-robins.

III. **False.** 50% of model eggs that were not accepted were ignored by the magpie-robins, compared to the 85% ignored by shamas. This indicates that shamas were faced with greater uncertainty.

IV. **False.** From the results, shamas still rejected 12% of the model eggs even though the population of shamas are not exploited by brood parasites. This suggests that egg rejection is evolutionary.

V. **False.** We cannot conclude the statement from the data provided, but in any case, egg retrieval is a fixed action pattern that is not learned.

Credits:

Modified from Yang, C., & Zhang, Z. (2024). Dynamics of evolutionary succession and coordination between opposite adaptations in cuckoo hosts under antagonistic coevolution. *Communications Biology*, *7*(1). https://doi.org/10.1038/s42003-024-06105-9

Hard Ecology

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.

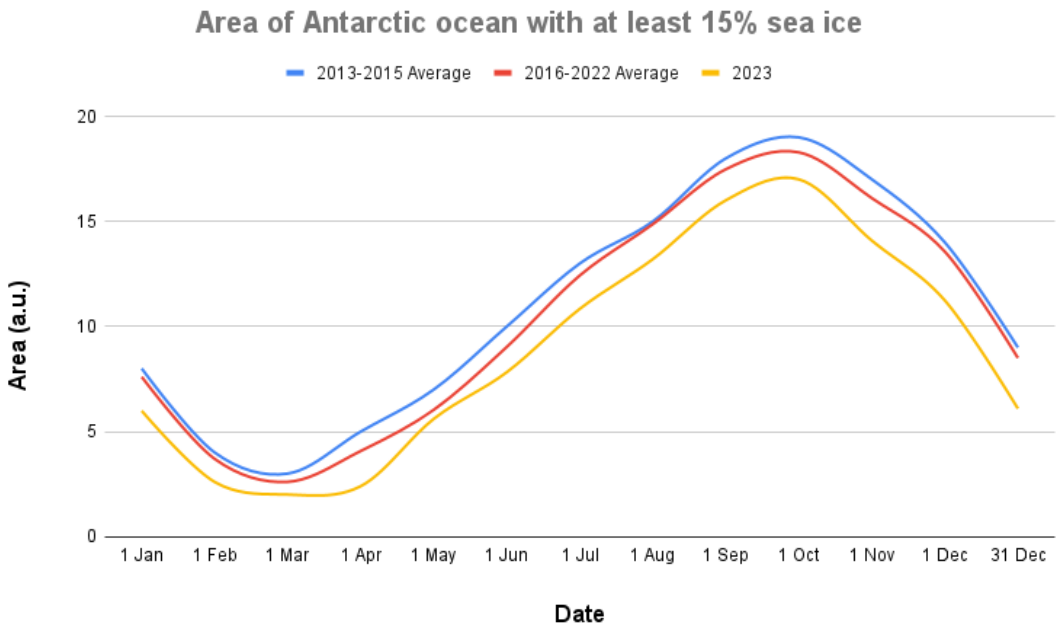


Figure 1: Sea ice extent in the Antarctic ocean

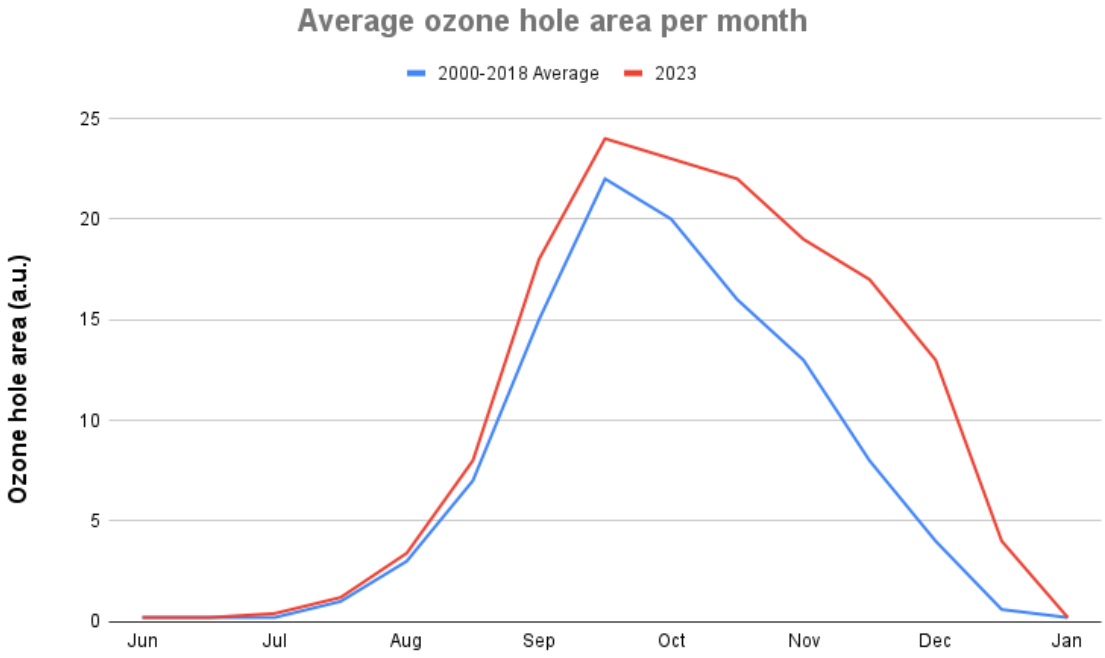


Figure 2: Average ozone hole area in each month

Hard Ecology

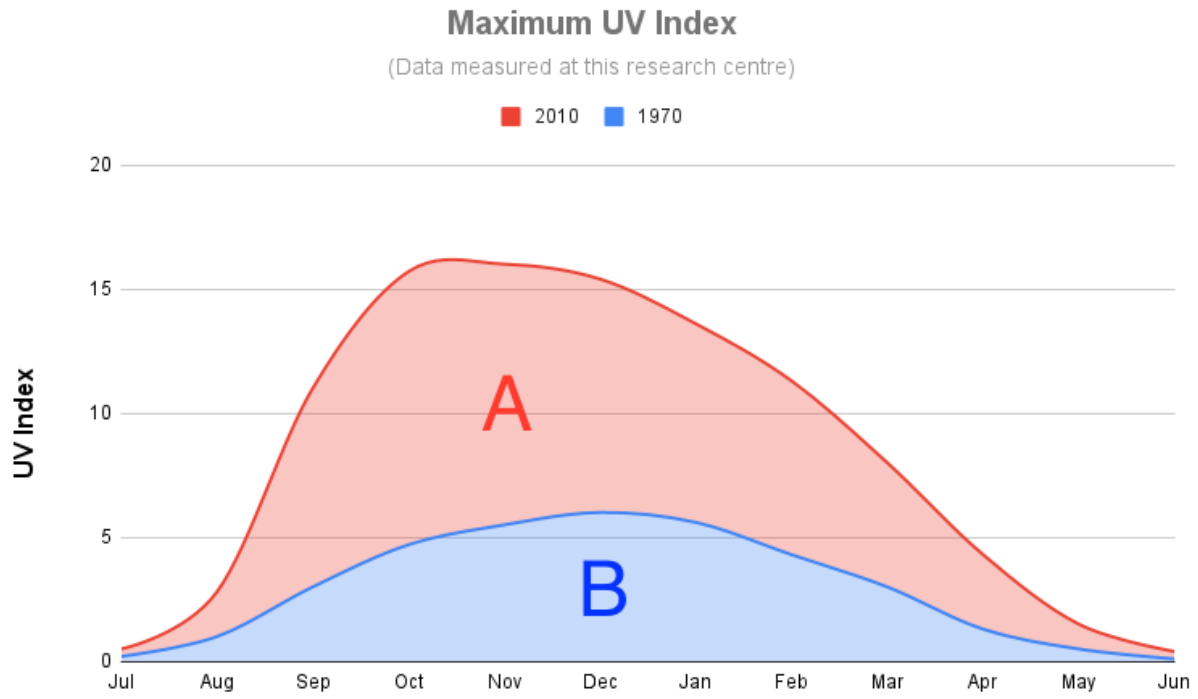


Figure 3: Maximum UV index measured by this research centre situated in Antarctica. The area between the two graphs is labelled A (red), while the area below the 1970 graph is labelled B (blue).

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

Hard Ecology

Answer: **A**

Explanation:

I. **False.** Although Figure 1 shows a decrease in sea ice cover between 2013 and 2023, the melting of sea ice does not contribute to rising sea levels.
II. **True.** Figure 2 shows an additional half month before the ozone hole layer returns to its minimal value in 2023 compared to the 2000-2018 average.
III. **False.** Carbon dioxide emissions do not deplete the ozone layer. Rather, chlorofluorocarbon emissions are mainly responsible for ozone depletion.
IV. **False.** Sea ice increases the reflectivity (albedo) of the ocean, and Figure 1 indicates a peak in sea ice cover in the September-October period compared to the November-December period. Hence, more UV radiation is reflected away from the ocean in September than December.

Content References:

2023 Antarctic Sea Ice Winter maximum is lowest on record by a wide margin. NATIONAL SNOW AND ICE DATA CENTER. (2023, September 25). https://www.climate.gov/news-features/event-tracker/2023-antarctic-sea-ice-winter-maximum-lowest-record-wide-margin

Robinson, S. A., Revell, L. E., Mackenzie, R., & Ossola, R. (2024). Extended ozone depletion and reduced snow and ice cover—consequences for Antarctic biota. *Global Change Biology*, *30*(4). https://doi.org/10.1111/gcb.17283

Hard Ecology

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.

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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

Hard Ecology

Answer: **D**

Explanation:

I. **False.** Mullerian mimicry is the mimicry of warning signals, which neither moth exhibits.
II. **False.** The variable colouration of balladeer moths is not the result of the exploitation of ecological niches in a habitat that is characteristic of adaptive radiation.
III. **True.** The caterpillar exhibits aposematic colouration, a signal to predators that it is unfavourable to prey on. This is similar to that of the childe moth. Moths with aposematic colouration often have caterpillars with aposematic colouration, which serves the same purpose.
IV. **False.** For the balladeer moth to exhibit a range of wing colouration phenotypes, the balladeer moth must have a high genetic diversity. In contrast, the childe moth with aposematic colouration is selected for a consistent colouration that repulses predators.
V. **True.** Moths with cryptic colouration meant for camouflage are nocturnal as their camouflage is more effective at low levels of light. Moths with aposematic colouration may or may not have temporal activity patterns.

Credits:

Childe moth, balladeer moth, kabukimono moth, content reference: Modified from Nokelainen, O., Silvasti, S. A., Strauss, S. Y., Wahlberg, N., & Mappes, J. (2024). Predator selection on phenotypic variability of cryptic and aposematic moths. *Nature Communications*, *15*(1). https://doi.org/10.1038/s41467-024-45329-5

Unknown caterpillar: Modified from Descouens, D. (2010, July 24). *Papilio machaon Linnaeus 1758*. Wikipedia. https://en.wikipedia.org/wiki/File:Chenille_de_Grand_porte_queue_(macaon).jpg