Problem Set Overview

The Youth STEM Cup (YSC) consists of two rounds: the **Preliminary Round**, and the **Final Round**. The questions in both rounds are designed for high school and pre-university students, and will test their knowledge across **six subjects** i.e. **Biology, Chemistry, Physics, Mathematics, Planetary Sciences** and **Social Science**. This sample problem set is created through the concerted efforts of the YSC Problem Selection Committee and the International Science Olympiad alumni. It gives an indication of the style of questions used in each round.

The general breakdown of paper in each round is described below:

- In **Preliminary Round**, the paper will consist of 36 questions - 6 questions from each subject mentioned above - to be sat in **one hour**. Participants can compete in **groups** or **individually**.
- In **Final Round**, the paper will consist of approximately 18 questions, with at least two questions from each subject. Each question is accompanied by a number of subquestions. The number of questions and subquestions in this round may change depending on the theme decided by the committee for that particular year. Participants will compete in **groups only** and have **two hours** to complete the paper.

To ensure fairness of the entire competition, participants will be divided into two different categories based on their academic level, which are **Junior category (SPM/O-level)** and **Senior category (STPM/Pre-U)**. Each category will have its own leaderboard and problem set.

For the paper in the Final Round, the theme changes every year and may influence the way questions are set. In general, there will be a few questions under a theme which may be arranged either in a sequence to form a storyline (shown below) or as individual questions related to the theme (see Final Round of YSC 2024).

The syllabus for all subjects will be at **SPM to Pre-U level** for **Junior category**, and at **Pre-U to National International Science Olympiads (ISO) selection test level** for **Senior category**. However, due to the lack of astronomy, astrophysics, planetary science and social science content in all three syllabi, the syllabus for these subjects will be stated and published on our official AMISO website to allow participants to prepare in advance. Any knowledge beyond the syllabus that will be tested will also be stated and published on our official website. To encourage self-studying on knowledge outside of curriculum, we have provided reading materials for every subject on our official website.

We hope this provides you with a clear understanding of how the questions are set and what to expect in YSC.

P.S. Not all of the problems in this sample problem set are cross-checked due to the fact that the problem setters are not proficient in all fields of science, do inform us if there are any mistakes and errors.

Acknowledgements

Special thanks to the YSC Problem Selection Committee and International Science Olympiad alumni for their contributions in creating this sample problem set:

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Contents

Youth STEM Cup
Sample Problem Set

(Senior Category)

Preliminary Round

Problems

Biology

1. Restriction endonucleases are used to cut the flanking sequences of cDNA. There are a few types of restriction endonucleases, which include overhang cutting enzymes and blunt end cutting enzymes. What is a possible benefit of using an overhang end cutting enzyme instead of a blunt end cutting enzyme?

    A. The active site of the enzyme is more specific, and thus there is less risk of mistakes in cutting out the gene.

    B. DNA fragments cut with the same overhang end cutting enzyme can reanneal.

    C. The overhang end cutting enzyme usually has faster turnover rates and higher yield.

    D. The overhang end cutting enzyme is resistant to higher temperatures and pH changes.

2. The Schwann cells are responsible for the myelination of neurons. As the myelination is discontinuous, nodes of Ranvier are formed across the axon, where action potentials occur. This allows for saltatory conduction, speeding up the conduction of each action potential. Which of the following is a possible explanation for this mechanism?

    A. The Schwann cells prevent ion movement across the membrane, preventing action potentials from occurring at these myelinated areas.

    B. The Schwann cells are electrical insulators, stopping the electrical conduction of the action potential across the myelinated areas.

    C. The Schwann cells secrete an inhibitor molecule which binds to the sodium-potassium pump, preventing active transport of the ions.

    D. The Schwann cells are small enough to enter the axon, directly stopping ion movement through the axon.

3. Artificial selection is a method which involves a method known as selective breeding. Compared to natural selection, there are many significant differences between the two. Which of the following is a characteristic of artificial selection, and not natural selection?

    A. It involves an agent of selection.

    B. It maintains genetic diversity and variation.

    C. It leads to evolution.

    D. It leads to a loss of alleles.

Chemistry

1. K of the following chemical reaction at 5 bar, 400°C is given:

$$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g) \qquad K = 5.92\times10^{-4}$$

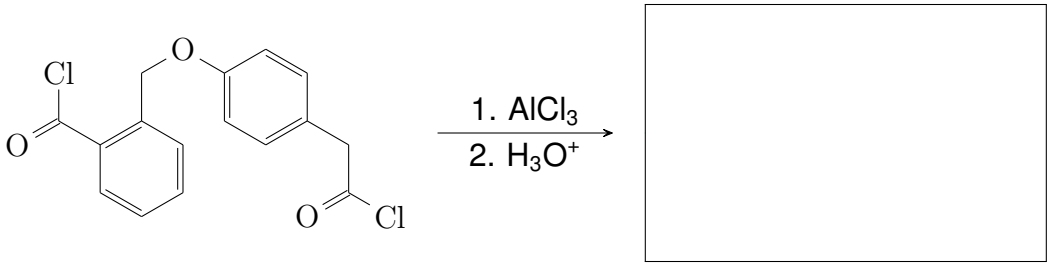
Find the enthalpy change of the reaction (in kJ/mol) if K at 5 bar, 500°C is 7.10×10^{-5}. (R = 8.314 J/K/mol)

A. −91.8
B. +91.8
C. −86.8
D. +86.8

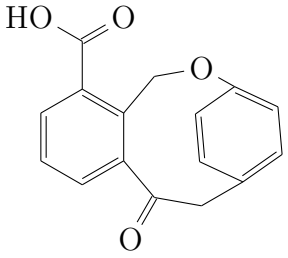
2. Which of the following molecule is the most Lewis acidic?

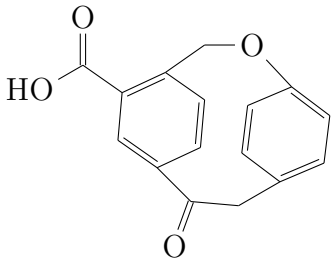
A. BF_3
B. BCl_3
C. BBr_3
D. BI_3

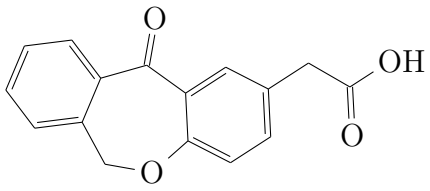
3. The reaction below depicts one of the steps in the synthesis of a certain compound.

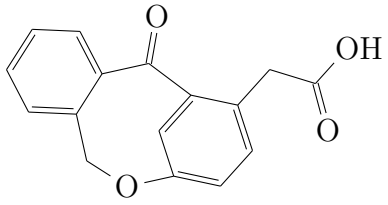


What is the major product of this reaction?

A.


B.


C.


D.


Physics

1. A boat of mass M and length L is some distance d away from the shore. Zhi Qi, of mass m, is standing on the back of the boat, i.e. the end farthest away from the shore. If she walks towards the front of the boat, what would the change in the distance of the boat to the shore Δd be?

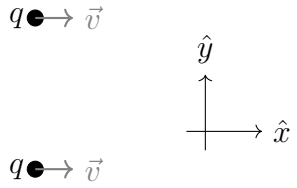
   A. $\frac{m}{M}L$

   B. $\left(\frac{m}{m+M}\right)^2 L$

   C. $\frac{m}{m+M}L$

   D. $\frac{mM}{(m+M)^2}L$

2. Two charges move with a non-relativistic velocity v in the $+\hat{x}$ direction, separated by a distance d. What is the force that a charge exerts on another, and are the charges attractive or repulsive?



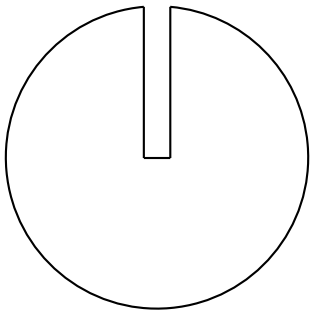
   A. $\frac{q^2}{4\pi\varepsilon_0 d^2}\left(1+\frac{v}{c}\right)$, repulsive

   B. $\frac{q^2}{4\pi\varepsilon_0 d^2}\left(1+\frac{v^2}{c^2}\right)$, attractive

   C. $\frac{q^2}{4\pi\varepsilon_0 d^2}\left(1-\frac{v^2}{c^2}\right)$, repulsive

   D. $\frac{q^2}{4\pi\varepsilon_0 d^2}\left(1-\frac{v}{c}\right)$, attractive

3. Consider a solid, spherical planet of radius r and uniform density ρ. A narrow shaft is drilled from the surface to the center as shown below. Below the surface, the temperature is constant at T_0. If this planet has an atmosphere with molar mass μ and surface atmospheric pressure p_S, find the air pressure at the bottom of the shaft.



   A. $p_S \exp\left(\frac{G\rho\mu r^2}{RT_0}\right)$

   B. $p_S \exp\left(\frac{\pi G\rho\mu r^2}{3RT_0}\right)$

   C. $p_S \exp\left(\frac{2\pi G\rho\mu r^2}{3RT_0}\right)$

   D. $p_S \exp\left(\frac{4\pi G\rho\mu r^2}{3RT_0}\right)$

Mathematics

1. Let a, b and c be 3 nonreal complex numbers, such that $abc = 1$. If none of $|a|$, $|b|$, $|c|$ is one or zero, choose the tightest bound for $|a|+|b|+|c|$ such that $a+b+c$ and $1/a+1/b+1/c$ are reals.

   A. No solution for a, b and c.

   B. $0 \leqslant |a| + |b| + |c| \leqslant 1$

   C. $0 \leqslant |a| + |b| + |c| \leqslant 10^6$

   D. $0 \leqslant |a| + |b| + |c| \leqslant K$ for some finite constant $K > 10^6$

   E. $|a| + |b| + |c|$ is unbounded

2. Let ABC be a non-degenerate triangle. If $x,\ y,\ z$ are reals such that $x^2 + y^2 + z^2 = 1$, what is the maximum of $yz \cos A + zx \cos B + xy \cos C$?

   A. 1

   B. 2

   C. 0.5

   D. $\sqrt{2}$

3. For $A \subset \mathbb{Z}_{>0}$, let
$$A_\varphi = \{\varphi^{(k)}(m) \mid m \in A, k \in \mathbb{Z}_{\geqslant 0}\},$$
   where φ is the Euler's Totient Function and $\varphi^{(0)}(m) = m$, $\varphi^{(k)}(m) = \varphi(\varphi^{(k-1)}(m))$.

   For some $n \in \mathbb{Z}_{>0}$, there exist A with n elements such that exist exactly n pairs of $(r, s) \in {A_\varphi}^2$ satisfying $\varphi(r) = s$. Jun Khye put all such n into a set, what could the set be?

   A. $\mathbb{Z}_{>0}$

   B. $\mathbb{Z}_{>0} \backslash \{p \mid p \text{ is prime}\}$

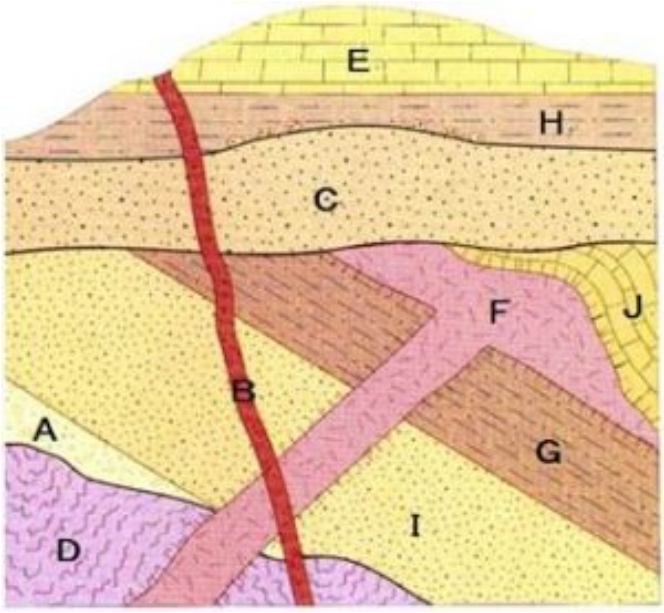
   C. $\mathbb{Z}_{>t}$ for some sufficient large t

   D. $\{1\}$

   E. None of the above

Planetary Science

1. Determine the correct chronological order for the formation of the following rock sequence.



A. A → B → C → E → F → G → I → J → D → H
B. D → A → I → G → F → J → C → H → E → B
C. D → F → A → I → G → J → C → B → H → E
D. E → H → C → D → A → B → I → G → F → J
E. D → F → A → B → I → G → J → C → H → E

2. We can roughly estimate the distance distant objects from us by using Hubble's law,

$$v = H_0 d$$

where v is recessional velocity (the speed of the object moving away from us) and H_0 is the Hubble's constant.

Hyades, a famous cluster in Taurus, has a parallax of 0.022″. Take H_0 = 70 km/s/Mpc, calculate the recessional velocity of the Hyades.

Tips: 1 parsec (pc) = 3.26 light-years (ly)

A. 0.98 m/s
B. 1.78 m/s
C. 3.18 m/s
D. 10.11 m/s

3. The following image depicts an outcrop located in Terran Wash, United States.

Name the type of fault shown in the photo.

A. Strike-slip fault
B. Normal fault
C. Reverse fault
D. Listric fault

Social Science

1. Alex and Bob are two workers in a factory. Each person's output is RM80 if they are lazy and RM170 if they work hard. The cost of effort is RM0 if they are lazy and RM50 if they work hard. The total output is shared equally between them. If both workers are completely selfish, then in the equilibrium outcome they will each end up with a net income of:

   A. RM50
   B. RM80
   C. RM90
   D. RM120

2. A perfect competition is an ideal market structure where many sellers compete with each other, and large sellers have no advantages over small ones. Which of the following is a valid characteristic of a perfect competition?

   A. Buyers have perfect knowledge of market conditions and the price that is charged.
   B. Products can vary based on quality.
   C. The barrier of entry for firms is low, but still exists.
   D. An alteration in the output of a firm may affect the market price.

3. Here are some sentences in the Abma Language and their English Translations.

Abma	English Translation
Mwamni sileng.	He drinks water.
Nutsu mwatbo mwamni sileng.	The child keeps drinking water.
Nutsu mwegau.	The child grows.
Nutsu mwatbo mwegalgal.	The child keeps crawling.
Mwerava Mabontare mwisib.	He pulls Mabontare down.
Mabontare mwisib.	Mabontare goes down.
Mwelebte sileng mwabma.	He brings water.
Mweselkani tela mwesak.	He carries the axe up.
Mabontare mworob mwesak.	Mabontare runs up.

Extra Information:
Abma is an Austronesian language spoken in parts of the South Pacific island nation of Vanuatu by around 8,000 people.

In the Abma sentences you read above, there is no separate word for 'the' or 'he'.

Translate “Mabontare keeps pulling him up” into English.

A. Mwatbo mwerava mwisib.
B. Mabontare mwatbo mwerava mwesak.
C. Mwatbo mwerava Mabontare mwisib.
D. Mabontare mwerava mwatbo mwesak.

Solutions

Biology

1. **B**

   The ends of cDNA which are cut out with the same restriction endonucleases have "overhang" ends which have exposed complementary base sequences. These are known as sticky ends. Thus, they can easily reanneal with other similar sticky ends of cut plasmids.

2. **A**

   The Schwann cells wrap around the axon, insulating it against ion movement across the axon membrane, thereby preventing action potentials from being generated at these myelinated areas. Because of this, action potentials can only be generated at the nodes of Ranvier, thus speeding up the conduction of action potentials.

3. **D**

   In artificial selection, the selective breeding method results in offspring that are uniform for a human-desired trait. This greatly reduces the genetic variation of the offspring, and thus leading to a loss of alleles.

Chemistry

1. **A**

   This question can be solved by using van't Hoff equation shown below:

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta H^\circ_{rxn}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

   where

$$\begin{aligned} K_1 &= \text{equilibrium constant at temperature } T_1 \\ K_2 &= \text{equilibrium constant at temperature } T_2 \\ \Delta H_{rxn} &= \text{enthalpy change of reaction in J/mol} \\ R &= 8.314 \text{ J/K/mol} \\ T_1 &= \text{temperature } T_1 \text{ in Kelvin} \\ T_2 &= \text{temperature } T_2 \text{ in Kelvin} \end{aligned}$$

   Let's work out the solution.

$$\begin{aligned} \ln\left(\frac{7.1 \times 10^{-5}}{5.92 \times 10^{-4}}\right) &= \frac{\Delta H^\circ_{rxn}}{8.314}\left(\frac{1}{673.15} - \frac{1}{773.15}\right) \\ \Delta H_{rxn} &= -91800 \text{ J/mol} \\ &= \boxed{-91.8 \text{ kJ/mol}} \end{aligned}$$

Extra information:

The van't Hoff equation is an important and useful equation to describe the effect of temperature on equilibrium constant. Its derivation is not taught much in Pre-U, so we'll demonstrate it here.

Recall that the Gibbs free energy can be expressed as:

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \qquad \text{and} \qquad \Delta G^\circ = -RT\ln K$$

Combining both equations together, you'll get:

$$-RT\ln K = \Delta H^\circ - T\Delta S^\circ$$
$$\ln K = \frac{-\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R} \quad \text{(van't Hoff equation)}$$

In order to obtain the van't Hoff equation shown in the solution above (i.e. equation (3) below), consider running the same reaction but at different temperatures, T_1 and T_2 which yields K_1 and K_2 respectively:

$$\ln K_1 = \frac{-\Delta H^\circ}{RT_1} + \frac{\Delta S^\circ}{R} \tag{1}$$

$$\ln K_2 = \frac{-\Delta H^\circ}{RT_2} + \frac{\Delta S^\circ}{R} \tag{2}$$

(2)$-$(1) gives:

$$\ln K_2 - \ln K_1 = \frac{-\Delta H^\circ}{RT_2} + \frac{\Delta S^\circ}{R} - \left(\frac{-\Delta H^\circ}{RT_1} + \frac{\Delta S^\circ}{R}\right)$$

After cancelling out $\frac{\Delta S^\circ}{R}$, factoring out $-\frac{\Delta H^\circ}{R}$ and finally rearranging the formula, we'll have:

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{-\Delta H^\circ}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) + \cancel{\frac{\Delta S^\circ}{R}} - \cancel{\frac{\Delta S^\circ}{R}}$$

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta H^\circ}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \tag{3}$$

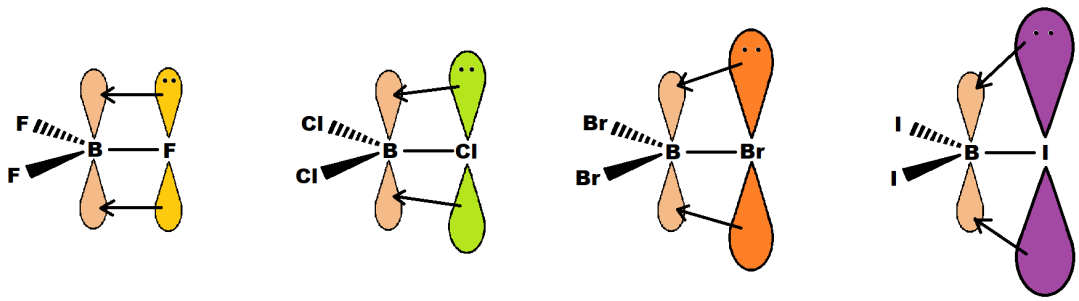
There is another method to derive equation (3), which is shown in this link: https://www.doubtnut.com/qna/647807612

Take note that, when using either formula, there is an underlying assumption that ΔH° and ΔS° do not vary with temperature, which means they are assumed to be constant over a short range of temperatures.

2. **D**

In this question, it's important to understand the definition of an acid using Lewis theory, also known as Lewis acid. A Lewis acid is an electron-pair acceptor. Examples of Lewis acid include boron trihalides in this question, metal ions in coordination complexes, hydrogen ion and many more.

The reason why BI_3 is the most Lewis acidic is because the back-bonding ($p\pi - p\pi$) interaction is the weakest for BI_3 due to the energy difference between 2p orbital of boron vs 5p orbital of iodine. This makes the orbital overlap weaker, thus causing the the boron atom in BI_3 being the most electron deficient species among the four boron trihalides.



The extent of back-bonding: **(2pπ—2pπ) > (2pπ—3pπ) > (2pπ—4pπ) > (2pπ—5pπ)**

Lewis acidity: **BF_3 < BCl_3 < BBr_3 < BI_3**

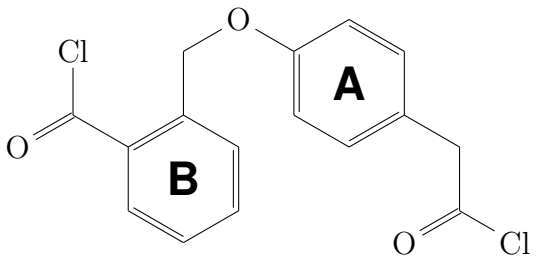
To learn more about back bonding, you may refer to these links:

- https://www.chemzipper.com/2018/12/back-bonding.html?m=0
- https://byjus.com/jee/back-bonding/

3. **C**

Although this question falls under the topic of electrophilic aromatic substitution (more specifically, Friedel-Crafts acylation), which is covered in the Pre-U chemistry syllabus, you only learn about this reaction involving monosubstituted benzene, while the same reaction involving disubstituted benzene is beyond the syllabus. So, it's highly recommended to read through this super useful article by Master Organic Chemistry: Disubstituted Benzenes: The Strongest Electron-Donor "Wins" to better understand electrophilic aromatic substitution in **disubstituted benzene**, to which the explanation below relates.

We hope that the article has expanded your knowledge about eletrophilic aromatic substitution. Let's dive into the explanation for this question.



Both benzene rings **A** and **B** have two substituents attached to them where the former has an ether group (−OR) and an alkyl group (−R) attached while the latter has an acyl group (−COR) and also an alkyl group (−R) attached.

The ether and alkyl groups are electron donating groups by means of resonance effect and positive inductive effect respectively, which increases the electron density of the benzene ring. Thus, they are known as the activating groups, with ether group being the stronger one. On the other hand, the acyl group is an electron withdrawing group which reduces the electron density of the benzene ring, making it the deactivating group.

For the above reasons, benzene ring **A** is more activated than benzene ring **B**, making benzene ring **A** more favoured in electrophilic aromatic substitution. We can therefore **rule out** options A. and B., leaving us with options C. and D. As for which of these two options is the correct answer, you'll have to recall what you've learned from the article we shared.

Both the ether and alkyl groups are activating groups, hence are *ortho-* and *para-* directing. Since *para*-position is occupied, we are only left with *ortho*-positions. As mentioned earlier, the ether group is a more activating substituent than the alkyl group (because it is a better electron-donor), the substituent will end up *ortho* to the ether group, not *ortho* to the alkyl group. This leads us to $\boxed{\text{C}}$ being the major product.

On a side note, the reason why the products stated in options A. and B. are not produced is because not only benzene ring **B** is LESS activated due to the acyl group attached to it, but also the formation of 10- and 12-membered rings would cause the benzene rings to distort out of plane, rendering them conformationally unfavoured.

Physics

1. $\boxed{\textbf{C}}$

The key idea here is that the center of mass of the whole system doesn't move, since the boat and Zhi Qi are an isolated system and all frictional forces involved in walking are internal. Choose the origin to be at the shore. The center of mass before Zhi Qi moves is

$$x_{cm} = (d_0 + L)m + \left(d_0 + \frac{L}{2}\right) M$$

. After the move, this expression becomes

$$x_{cm} = d_1 m + \left(d_1 + \frac{L}{2}\right) M$$

Setting these two expressions equal to each other, we obtain

$$\Delta d = d_1 - d_0 = \boxed{\frac{m}{m+M}L}$$

2. **C**

Call the charge on top 1 and the one below 2. The magnetic field generated by a charge moving at non-relativistic speeds can be expressed with the Biot-Savart law, $\vec{B} \approx \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\vec{r}}{r^3}$. The electric field is straightforward, $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q\vec{r}}{r^3}$. Putting these all together, the Lorentz force law gives

$$\begin{aligned}
\vec{F}_{\text{on 1, by 2}} &= q(\vec{E_2} + \vec{v_1}\times\vec{B_2}) \\
&\approx q\left(\frac{1}{4\pi\varepsilon_0}\frac{q(d\hat{y})}{d^3} + (v\hat{x})\times\frac{\mu_0}{4\pi}\frac{q(v\hat{x})\times(d\hat{y})}{d^3}\right) \\
&= q\left(\frac{q}{4\pi\varepsilon_0}\frac{\hat{y}}{d^2} + \frac{q}{4\pi\varepsilon_0 c^2}\frac{v^2}{d^2}\hat{x}\times(\hat{x}\times\hat{y})\right) \\
&= \frac{q^2}{4\pi\varepsilon_0 d^2}\left(\hat{y} + \frac{v^2}{c^2}(-\hat{y})\right) \\
&= \boxed{\frac{q^2}{4\pi\varepsilon_0 d^2}\left(1-\frac{v^2}{c^2}\right)\hat{y}}
\end{aligned}$$

3. **C**

The motivation for this problem is to use the hydrostatic pressure gradient condition:

$$\frac{dp_A}{dr} = -\rho_A(r)|\vec{g}_{\text{eff}}(r)|$$

This comes from considering an infinitesimal shell of air around the planet of thickness dr, and applying Newton's 2nd law to it (exercise left to reader). Since the shaft is narrow, we can ignore its thickness. Using Newton's shell theorems, we can get

$$\vec{g}_{\text{eff}} = -\frac{4\pi G\rho}{3}\vec{r}$$

with the origin set at the center of the planet. Note that ρ here is the density of the planet, not the air ρ_A. Then, by the ideal gas law we can rewrite the pressure gradient as

$$\frac{dp_A}{dr} = -\left(\frac{\mu p_A}{RT_0}\right)\left(\frac{4\pi G\rho}{3}r\right)$$

One can integrate this to get the pressure at the center of the planet p_C to be

$$\begin{aligned}
-\int_{p_C}^{p_S}\frac{dp_A}{p_A} &= \left(\frac{4\pi G\rho\mu}{3RT_0}\right)\int_0^r r\,dr \\
\ln\frac{p_C}{p_S} &= \left(\frac{2\pi G\rho\mu}{3RT_0}\right)r^2 \\
\boxed{p_C &= p_S\exp\left(\frac{2\pi G\rho\mu r^2}{3RT_0}\right)}
\end{aligned}$$

Mathematics

1. **A**

   Consider the polynomial

   $$(x-a)(x-b)(x-c) = x^3-(a+b+c)x^2+(ab+bc+ca)x-abc = x^3-(a+b+c)x^2+\left(\frac{1}{a}+\frac{1}{b}+\frac{1}{c}\right)x-1$$

   which is a polynomial in reals. Plotting the graph in $\mathbb{R}^2$ plane, then a cubic curve must have at least one real root by Intermediate Value Theorem, which contradicts to a, b and c being non-reals.

2. **C**

   We claim $x^2+y^2+z^2 \geqslant 2(yz\cos A + zx\cos B + xy\cos C)$ by completing the squares:

   $$x^2+y^2+z^2-2(yz\cos A+zx\cos B+xy\cos C) = [z-(x\cos B+y\cos A)]^2+[A\sin B-y\sin A]^2 \geqslant 0$$

   Then, the result follows directly. The equality can be attained by $(A,B,C) = \left(\frac{\pi}{3},\frac{\pi}{3},\frac{\pi}{3}\right)$ and $(x,y,z) = \left(\frac{1}{\sqrt{3}},\frac{1}{\sqrt{3}},\frac{1}{\sqrt{3}}\right)$. Clearly, one could use the calculus trick to kill this problem, either via tangent-line trick or Lagrange Multiplier.

3. **A**

   Consider $A = [n]$, then $A_\varphi = [n]$ because $\varphi(m) \leqslant m$. Thus, only $(m, \varphi(m)), 1 \leqslant m \leqslant n$ satisfy $\varphi(r) = s$, there are exactly n pairs.

Planetary Science

1. **B**

   When encountering such question, it's good to recall these principles:

   - **Principle of Superposition:** Rocks formed on top of another rock will be younger than the rock below it.
   - **Principle of Cross-cutting Relationships**: Any rock that cuts across another rock will be younger than the rock that it intersects.

   Based on these principles, the sequence of the stacks will be D → A → I → G → F → J → C → H → E, and since B cuts through all of them, it will be younger than all of them, hence B will be the last in the sequence. Also note the fact that rock F cuts through layers D, I, G meaning that F is younger than them.

2. **C**

   We first need to find our distance to the Hyades, which is equal to

   $$d(\text{in parsecs}) = \frac{1}{p}$$

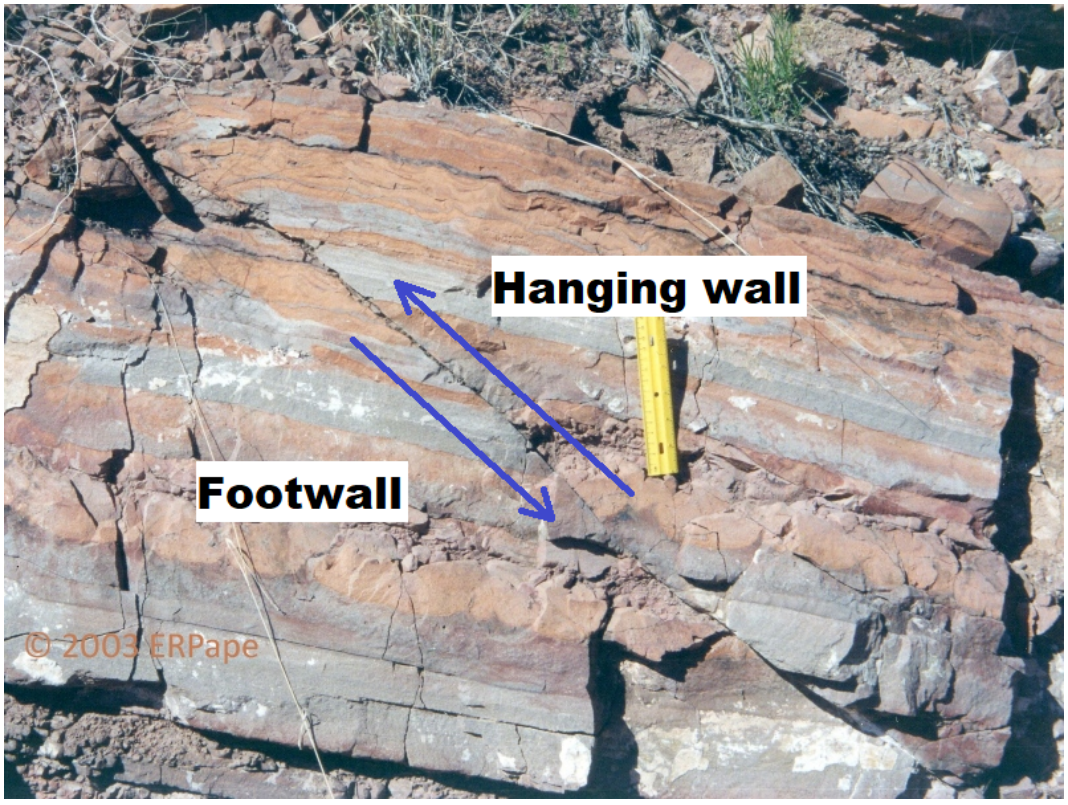
where p is the parallax (in arcseconds), which means that the Hyades is currently $\frac{1}{0.022}$ = 45.45 pc away from us. From here, we can use Hubble's Law to calculate the recessional velocity of the Hyades is

$$v = \frac{70 \times 45.45}{1000} = 3.1815 \approx \boxed{3.18 \text{ m/s}}$$

3. **C**

In faults like this, you need to first identify the hanging wall and the footwall. The hanging wall is like a cliff (flat surface on top and then a steep slope directly underneath it). Secondly, find out whether the hanging wall is up or down relative to the footwall. We can do that by comparing the layers of rock. If the hanging wall has moved down relative to the footwall, it is known as a normal fault. However, if the hanging wall has moved up relative to the footwall, it is known as a reverse fault. You can do this by marking where the similar layers of rock are.

As we can see from the image below, the hanging wall and footwall have been identified. Since the hanging wall moved up relative to the footwall, it is therefore a **reverse fault**.



Social Science

1. **B**

Since working hard costs RM50 − RM0 = RM50 more but only results in (RM170 − RM80)/2 = RM45 of profit, so no one will work hard. Hence, the cost of effort is RM0, and the joint output is RM160, which is shared equally so they each will receive RM80.

2. **A**

Let's understand why A is the answer:

- In a perfect competition, buyers will have perfect knowledge of market conditions and the price. Everything is transparent and no information is hidden. Hence, **A** is the **answer**.
- Within a perfect competition, products have to be identical and homogenous (i.e. the quality, shape, size, colour etc of the products do not vary). Hence, **B** is **wrong**.
- There is zero barrier of entry for firms within a perfect competition. So, **C** is **wrong**.
- In a perfect competition, each firm only makes a small contribution to the total supply in the market. Hence, it is impossible for an alteration to affect the market price which makes **D** a **wrong** answer.

3. **B**

As you look through the table, you may have been able to catch what each Abma word means in English:

mwamni	=	drink
sileng	=	water
nutsu	=	child
mwatbo	=	keep
mwegau	=	grow
mwegalgal	=	crawl
mwerava	=	pull

mwisib	=	down/go down
mwelebte	=	bring
mweselkani	=	carry
tela	=	axe
mworob	=	run
mwesak	=	up

More importantly, by analyzing each sentence in Abma language, you may notice that all of them follow the same sentence structure i.e. Subject – Verb – Object, with either inclusive of all components or absence of the Subject or Object. For example:

∅	**Nutsu**	**mwatbo**	**mwamni**	**sileng**
The	child (Subject)	keeps	drinking (Verb)	water (Object)

All components are included.

∅	**Mwerava**	**Mabontare**	**mwisib**
He (Subject)	pulls (Verb)	Mabontare (Object)	down

Since there's no separate word for 'he', the sentence structure will be Verb – Object. The same applies to "Mwamni sileng", "Mwelebte sileng mwabma" and "Mweselkani tela mwesak".

Mabontare	**mwisib**
Mabontare (Subject)	goes down (Verb)

In this case, there is no Object, so the sentence structure will be Subject − Verb. The same applies to “Nutsu mwegau”, “Nutsu mwatbo mwegalgal” and “Mabontare mworob mwesak”.

Using the same concept, “Mabontare keeps pulling him up” can be broken down as such:

Mabontare (Subject)	keeps	pulling (Verb)	him (Object)	up
Mabontare	**mwatbo**	**mwerava**	∅	**mwesak**

Therefore, the answer is B.

References

Physics

1. **Q3** is adapted from Problem 32 of:
   Gnadig P, Honyek G, Vigh M, Riley KF. 200 More Puzzling Physics Problems With Hints And Solutions. Cambridge (England): Cambridge University Press; 2016.

Mathematics

1. **Q2** is sourced from:
   Andreescu T, Korsky S, Pohoata C. Lemmas in Olympiad Geometry. Plano (TX): XYZ Press; 2016.

Planetary Science

1. **Q1** is sourced from:
   Malaysian Earth Science Olympiad 2019 (Paper 1). Kuala Lumpur (MY): Ardent Educational Consultant; 2019 [cited 2024 Dec 30] Available from: https://myeso.com.my/sample-questions/

2. The image in **Q3** is sourced from:
   Pape E. GeoSnaps - Image of the Day [Image on the internet]. Teran Wash (AZ): Arizona Geology Magazine; 2003 [cited 2025 Jan 5]. Available from: https://azgeology.azgs.arizona.edu/azgs/image-of-the-day/images/reverse-fault-teran-wash

Social Science

1. **Q1** is adapted from:
   International Economics Olympiad 2024.

Youth STEM Cup
Sample Problem Set

(Senior Category)

Final Round

Problems

Section A: Beach

Je Qin decided to go for a holiday trip with his nerdy buddies! Because of the blazing hot tropical weather of Malaysia, the group decided to spend the day cooling down at a beach. Upon arriving at the site, they were greeted by a swarm of people, with a clear panoramic view of the ocean.

1. It is well known that seawater is salty, and the chemical formula of salt is NaCl. Joyton decided to measure the content of chloride ions in seawater, so he decided to use a mercurimetric titration method. The procedures are listed as follows:

   I. 9.8×10^{-2} mol/dm^3 of $Hg(NO_3)_2$ solution was prepared and placed in a burette.

   II. 0.500 mL of seawater sample was collected and added into a small conical flask.

   III. 2 mL of deionised water, 4 drops of 5 % HNO_3 and 3 drops of s-diphenylcarbazone (indicator) were added to the conical flask, the mixture was then titrated against the $Hg(NO_3)_2$ solution prepared above. 8.24 mL of $Hg(NO_3)_2$ solution was used.

   IV. To improve the accuracy of this experiment, Joyton wanted to conduct a blank titration. He first treated the seawater to ensure that all chloride ions were removed and then performed the titration using water with ten times the volume of the treated seawater sample. 0.80 mL of $Hg(NO_3)_2$ solution was used.

   It is known that Hg^{2+} reacts with chloride ions to form $HgCl_2$, which has a very small degree of ionisation ($K_{sp} = 4\times10^{-15}$ mol^3 dm^{-9}). The excess Hg^{2+} ions will form a purple complex with the indicator. Calculate the concentration of chloride ions in mg/100 mL. Provide your answer up to three significant figures.

2. Seeing as Joyton is quite busy with his analyses, Kian Yau wants to keep himself occupied too. He wants to build a conical sandcastle with a radius of 5 cm. Given that the coefficient of friction of a sand grain to another sand grain is 0.3, and by considering the free body diagram of a sand grain at the edge of the cone, find the highest possible volume of the sandcastle that he could build.

3. As the sun was shining on the sea, it reminded Rayson about the water cycle of the Earth. From his secondary school years, he remembered that the Sun is responsible for sustaining rainfall on the planet by evaporating water. Using the Solar Flux, help Rayson determine the average global annual rainfall in mm/yr! Multiply your answer by 0.05 to account for the fact that not all sunlight reaches the Earth evenly and at once, due to the Earth's rotation and atmosphere. Also, give your estimate in 2 s.f.

   (Solar Flux = 1373 W/m^2, Latent heat of vaporization of water = 2260000 J/kg, Latent heat of fusion of water = 334000 J/kg, Density of water = 1000 kg/m^3)

4. Zhi Zheng, inspired by Rayson's fascination with the sun, decided to do an experiment to verify the value of the Solar Constant himself. He put 5 g of water in a small bottle cap, and took out a convex magnifying glass that he conveniently brought along, which had a

radius of R = 10 cm. After focusing sunlight on the sample of water for 5 minutes, all the water boiled away. Assuming all the energy came from the Sun, and that the temperature of Penang is 30℃, what would be the Solar Constant that Zhi Zheng gets, in 3 s.f.?

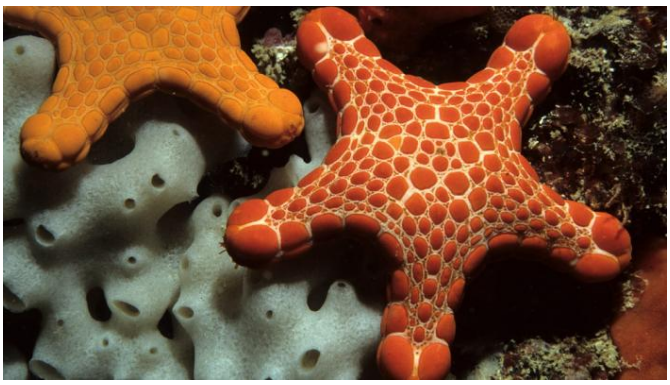
(Specific heat capacity of water = 4200 J/kg/K, Latent heat of vaporization of water = 2260000 J/kg, Latent heat of fusion of water = 334000 J/kg, Density of water = 1000 kg/m^3)

5. Ali is a marine biology enthusiast. He went to a marine paleontology museum and learnt a surprising fact. It was said that life first came from the ocean. Michael Russel, an independent researcher and prominent geologist once pointed out that life began in hydrothermal vents on the seabed, where warm water seeps up from geological formations below. Interactions between warm water and rocks would provide chemical energy that would first drive simple metabolic cycles, which would later start making and using chemicals such as RNA. Although hydrothermal vents are known to be able to sustain many food chains, plants are not found near them.

   Tick all reasons that apply.

   - ☐ Low light intensity
   - ☐ High pH of seawater
   - ☐ High pressure of seawater
   - ☐ High temperature of seawater
   - ☐ Low concentration of dissolved carbon dioxide near hydrothermal vents

6. An echinoderm is any member of the phylum Echinodermata. This includes starfish, sea cucumbers, brittle stars, etc. Adult echinoderms are found on the seabed of every ocean depth, making them the second-largest grouping of deuterostomes, after the chordates. Which of the following are common features of the phylum echinodermata?



   - ☐ Spiny skin
   - ☐ Exoskeleton
   - ☐ Water vascular system
   - ☐ Only capable of reproducing asexually
   - ☐ Capable of regenerating all organs

7. As Anzo and Ivan continued chilling in the shade, they realized that there was a peculiar bug moving on their square-lattice table that conveniently resembled coordinate axes. The bug only moved parallel to the x and y axes. Let A = (-3, 2) and B = (3, -2). Consider all possible paths of the bug from A to B of length at most 14. How many points with integer coordinates lie on at least one of these paths?

8. Kian Yau thought of a math problem when he was sunbathing. Let N be a positive integer. How many integers are between $\sqrt{N^2+N+1}$ and $\sqrt{9N^2+N+1}$? Express your answer in terms of N.

9. Ming Wen was neither sunbathing nor chilling in the shade, but was trying to solve a linguistic problem under a coconut tree.

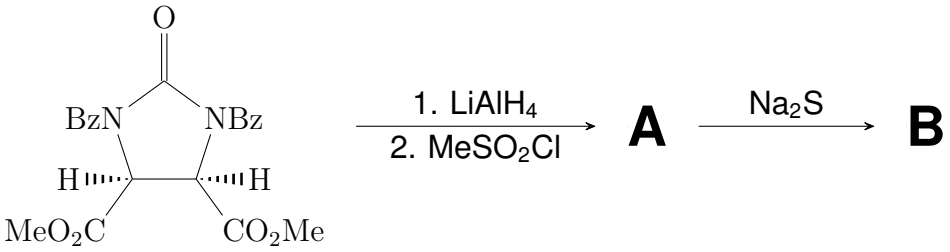
The picture on the left is a leaflet in Welsh, with English translations, about the library service in the Welsh county Gwynedd.

After looking through the leaflet, he was given a question:

> Use the leaflet to find the Welsh translations of "only request".
>
> A. ceisiadau unig yn
>
> B. yn unig ceisiadau
>
> C. ceisiad yn unig
>
> D. yn ceisiadau unig

Can you help him to solve this question so that he could enjoy his trip with his friends?

10. Aaron was scrolling through his phone and encountered a short article. It stated that hydrogen sulfide (H_2S) is one of the most important compounds that allows chemosynthesis to occur within organisms that live near hydrothermal vents. Needless to say, sulphur is also present in quite a number of nutrients in our body, such as proteins and vitamins. The reaction below is an important step in order to artificially produce one of the vitamins found in the human body. Suggest which of the following is the best combination of structures of **A** and **B**.

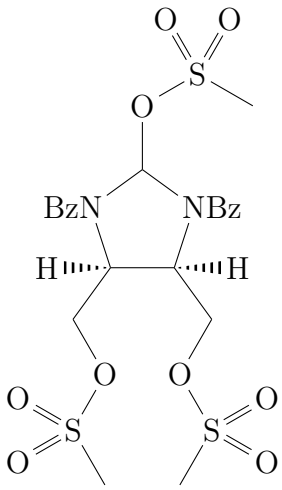


Note:

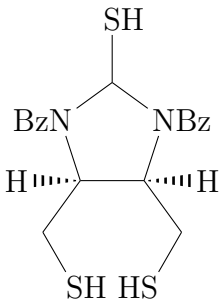
Bz =

Me = CH_3

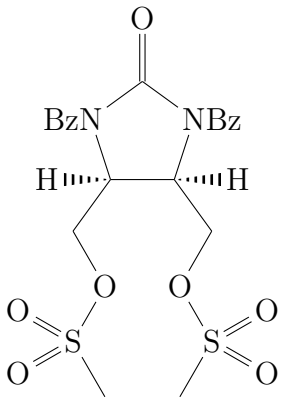
A. **A** =



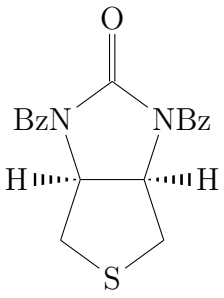
B =

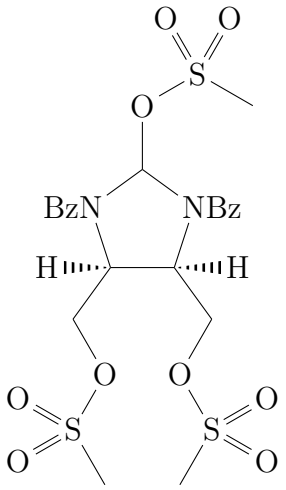


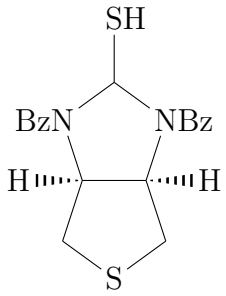
B. **A** =

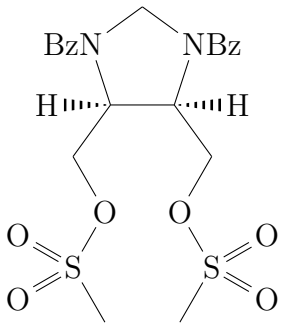


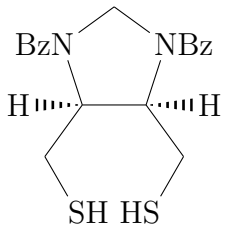
B =



C. **A** = 

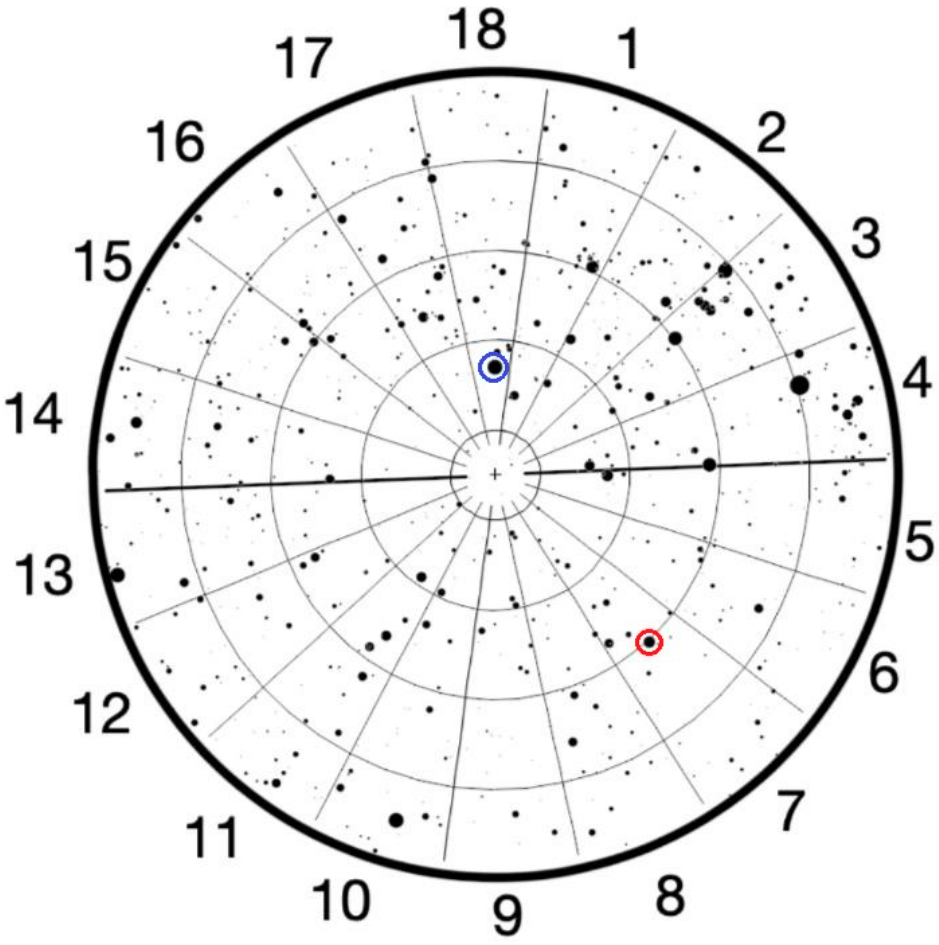
B = 

D. **A** = 

B = 

11. Ashwin was sipping his non-alcoholic cocktail when his father phoned him. He learnt from his father that he had just won an unbelievable lottery, which will pay him RM2,000 next year and then continue making regular annual payments to him (and his descendants) that increase by 3% each year forever. What will be the current fair price of these payments if the risk-free interest rate is 5%?

12. As the sun set, the group sat together to bask in the starlight. The diagram below shows their night sky.



(i) Give the names and constellations of the stars circled in red and blue respectively.

(ii) The brightest star in the night sky is also shown in the diagram. Which numbered segment is it in, and what is the star and constellation's name?

(iii) Estimate the latitude of the group's beach. Is it in the North or South hemisphere?

Solutions

Section A: Beach

1. **11300 mg/100 mL**

   In this question, the blank titration was conducted to detect the presence of and determine the amount of other impurities, other than Cl^- ions, in the seawater that reacted with Hg^{2+} ions to form precipitates. These additional precipitates contributed to titration errors and thus would affect the accuracy of the measured Cl^- ion concentration in the sample.

   So, we have to subtract the volume of titrant (i.e. $Hg(NO_3)_2$ solution) used to precipitate the impurities from the initial volume of titrant used in order to determine the true amount of Hg^{2+} ions that reacted with Cl^- ions:

   $$\begin{aligned}&\text{Volume of } Hg^{2+} \text{ ions that reacted with chloride ions}\\&= (8.24 - 0.8 \times 0.1)\ mL\\&= 8.16\ mL\end{aligned}$$

   From the equation below, Hg^{2+} ions reacts with Cl^- ions at molar ratio of 1:2.

   $$\mathrm{Hg^{2+}\,(aq) + 2\,Cl^-\,(aq) \longrightarrow HgCl_2\,(s)}$$

   Therefore, the concentration of Cl^- ions in the seawater is:

   $$\begin{aligned}\frac{n(\mathrm{Hg^{2+}})}{n(\mathrm{Cl^-})} &= \frac{1}{2}\\\frac{(8.16)(9.80 \times 10^{-2})}{(0.50)([\mathrm{Cl^-}])} &= \frac{1}{2}\\[\mathrm{Cl^-}] &= 3.199\ mol/dm^3\\&= (3.199 \times 35.45 \times 10^3)\ mg/1000\ mL\\&= 113000\ mg/1000\ mL\\&= \boxed{\text{11300 mg/100 mL}}\end{aligned}$$

2. **39.27 cm^3**

   The resultant force acting on the sandcastle has to be zero in order for it to be in equilibrium i.e. for it to be stable. By considering the free body diagram, the maximum angle of the slope to horizontal, is the coefficient of friction, μ.

   The volume of the conical sandcastle is:

   $$V_{\text{conical sandcastle}} = \frac{1}{3}\pi R^2 h$$

   Considering the aforementioned statement, the height of the conical sandcastle is:

   $$h = R\tan\theta = R\mu$$

Substitute into the formula for the volume of conical sandcastle, we'll get:

$$\begin{aligned} V_{\text{conical sandcastle}} &= \frac{1}{3}\pi R^2 h \\ &= \frac{1}{3}\pi R^2 (R\mu) \\ &= \frac{1}{3}\pi R^3 \mu \end{aligned}$$

Therefore, the highest possible volume of the conical sandcastle is:

$$V_{\text{conical sandcastle}} = \frac{1}{3}\pi R^3 \mu = \frac{1}{3}\pi(5^3)(0.3) = \boxed{39.27 \text{ cm}^3}$$

3. **960 mm/yr**

This problem can be solved with dimensional analysis.

Solar Flux, $F_\odot$ has units $\frac{J/s}{m^2}$, and the metric for rainfall is $\frac{m}{s}$, i.e. it's the height of water accumulated over a period of time.

To match their units,

$$\frac{J/s}{m^2} \times \frac{?}{?} = \frac{m}{s}$$

so therefore $\frac{?}{?} = \frac{m^3}{J}$, i.e. the reciprocal of an energy density.

Since evaporating all this water needs energy, the conversion factor must contain L_{vap}, which has units $\frac{J}{kg}$.

To make L_{vap} into an energy density, we can use the density of water:

$$L_{vap} \times \rho_{water} = \frac{J}{kg} \times \frac{kg}{m^3} = \frac{J}{m^3}$$

Therefore, the rainfall must be $\frac{F_\odot}{L_{vap}\rho_{water}} = 6.075 \times 10^{-7}\ m/s$

Converting the value to mm/yr, and multiplying by the fudge factor 0.05, we get:

$$0.05 \times 6.075 \times 10^{-7}\ m/s \times \left(\frac{3600\ s}{1\ hr}\right) \times \left(\frac{24\ hr}{1\ day}\right) \times \left(\frac{365.2422\ days}{1\ yr}\right) \times \left(\frac{1000\ mm}{1\ m}\right) = \boxed{960 \text{ mm/yr}}$$

4. **1350 W/m^2**

By conservation of energy, $E_{in} = E_{out}$.

Since Solar Flux is Power over Area, the input power is the solar flux multiplied by the

light collecting area of the lens:

$$\begin{aligned} F_{\odot} &= \frac{m_{water}(c\Delta T + L_{vap})}{A_{lens}t} \\ &= \frac{0.005\ kg \times [4200(100-30) + 2.26 \times 10^6]\ J/kg}{\pi \times (0.1\ m)^2 \times 5.60} \\ &= \boxed{1350\ \text{W/m}^2} \end{aligned}$$

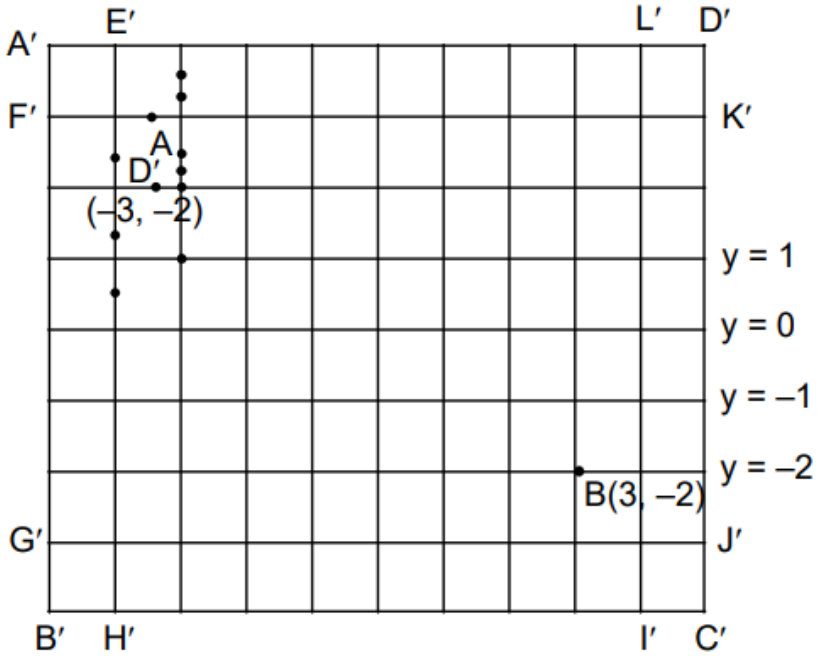
5. ☐ Low light intensity
   ☐ High pH of seawater
   ☑ High pressure of seawater
   ☑ High temperature of seawater
   ☐ Low concentration of dissolved carbon dioxide near hydrothermal vents

   Let's understand why only options 3 and 4 are correct:

   - Option 1 is **False**, because hydrothermal vents are located at more than 2000 meters below the surface of the ocean, which is known as abyssal zone, where there is zero light intensity.
   - Option 2 is **False**, because seawater around hydrothermal vents have low pH due to H_2S.
   - Option 3 is **True**, because high pressure of seawater would crush plants.
   - Option 4 is **True**, because high temperature would denature enzymes of plants.
   - Option 5 is **False**. Although hydrothermal vents have enriched CO_2 concentration, plants are unable to survive because of the extreme conditions aforementioned.

6. ☑ Spiny skin
   ☐ Exoskeleton
   ☑ Water vascular system
   ☐ Only capable of reproducing asexually
   ☐ Capable of regenerating all organs

7. **87**



With given condition, the bug can use all points except A′, F′, E′, B′, H′, G′, I′, C′, J′, K′, L′, D′ in his path. So, the total number of points in at least one of the path will be $11 \times 9 - 4 \times 3 = \boxed{87}$.

8. **2N**

$(N+1)^2 > N^2 + N + 1 > N^2$
So, $N+1$ is the first number.

$(3N)^2 < 9N^2 + N + 1 < (3N+1)^2$
So, $3N$ is the last number.

$\therefore \boxed{2N}$

9. **C**

From the leaflet, you might have noticed that Welsh exhibits these characteristics:

- Notice from the passages above that Welsh has a **Verb – Subject – Object** sentence structure.
- There are some singular-plural differences. You can find *llyfrau* translating "books" in several places and *ceisiadau* translating "requests", both of which bear the *-au* suffix – a plural marker for these words. However, in *Ceisiadau llyfrau*, it is translated as the singular: "book requests". To understand what is going on here, it's important to recognize that the English "book requests" means the same as "requests for books" (where "books" is plural). Therefore, the direct Welsh translation would adopt the plural form of "book requests" i.e. *ceisiadau llyfrau*.

On a side note, you may also notice that the singular form *llyfr* is found in *llyfrgell*, "library" as well – i.e. a direct translation from the meaning of a library which is a book-place (*gell* in fact means "place"). (You might find it helpful to relate *llyfr* to the French livre or even to the *libr-* of English *library*.)

- Another aspect of all Celtic languages including Welsh is 'mutation' which is somewhat peculiar, whereby initial consonants mutate (change) from one sentence context to another. This is why some words have two forms (e.g. *llyfrgell* or *lyfrgell*; *cyfrifiaduron* or *gyfrifiaduron*). You can spot that in the phrase *unrhyw lyfrgell*, "any library", where the *ll* of *llyfrgell* changes to *l*, and the same rule applies to constructing "any books".

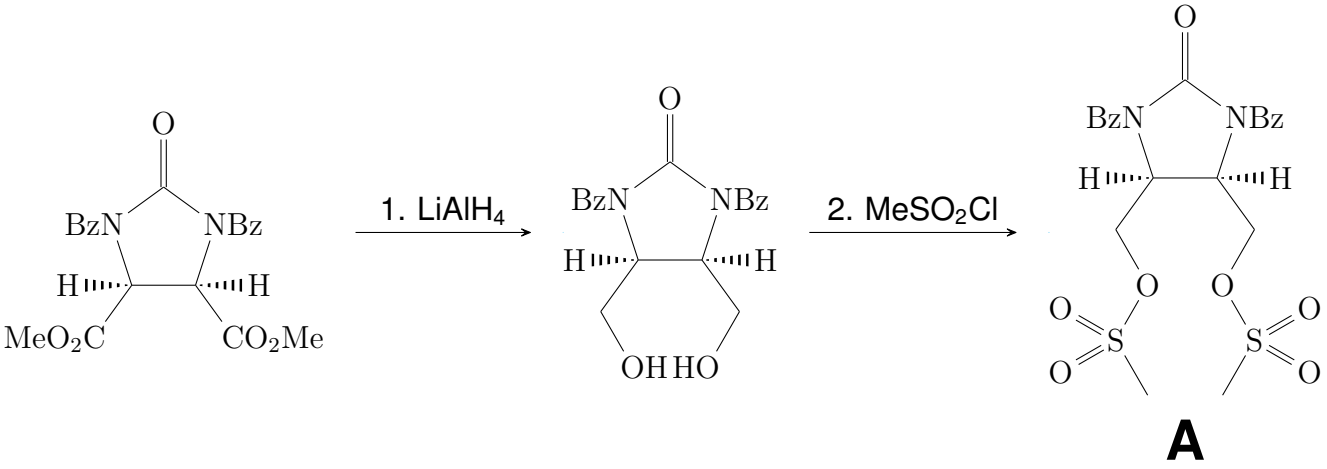
Let's get back to the question. This question is straightforward, as you only need to translate "only request" into Welsh by considering the aspects of sentence structure and plurality as shown below:

request	**only**
ceisiad	*yn unig*

Hence, the answer is C.

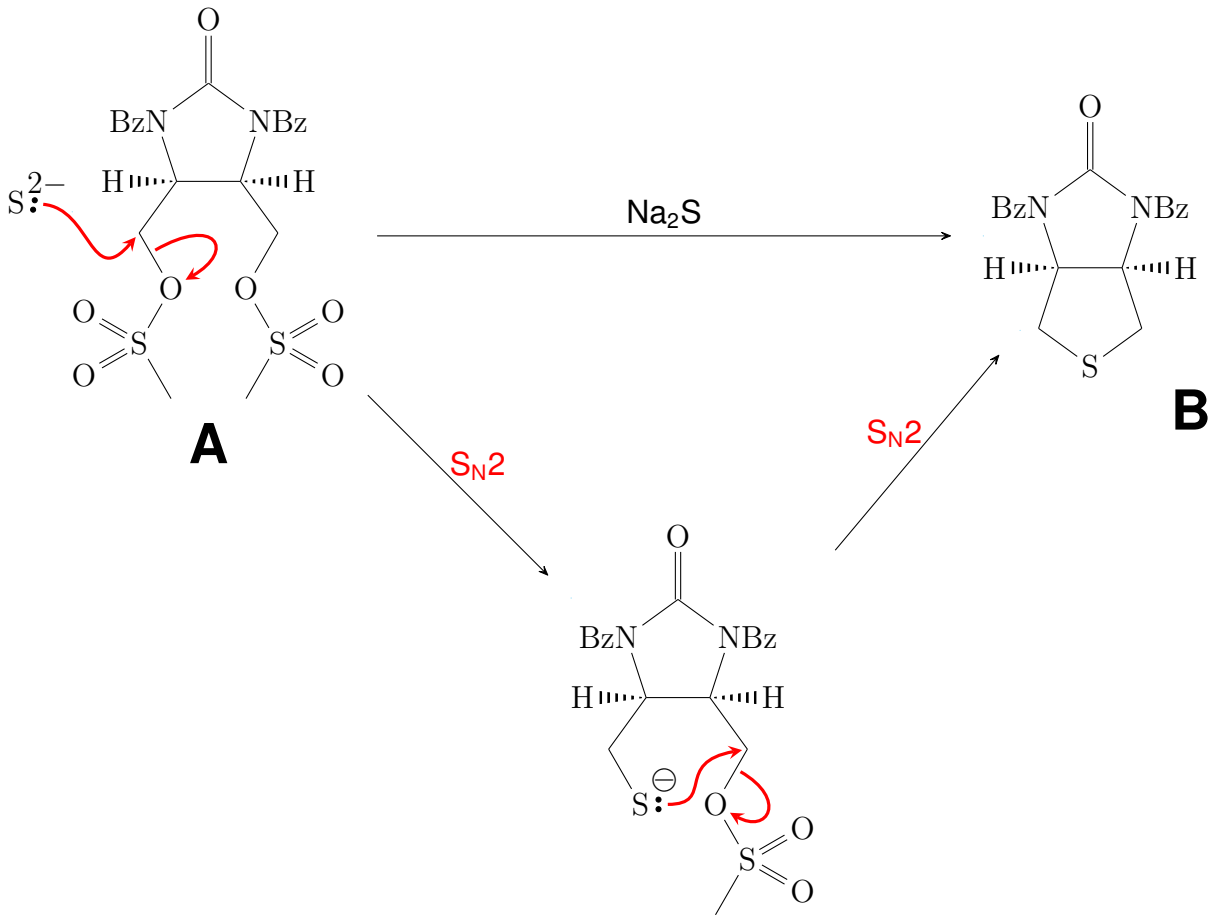
10. **B**

In the first step, the initial reaction involves the reduction of ester groups to primary alcohols while the second reaction involves the formation of mesylate groups from hydroxyl groups to produce better leaving groups, leading to the production of **A**.



A

In the subsequent step, the S^{2-} ion from Na_2S acts as a nucleophile and replaces the mesylate group via S_N2 reaction. The thiolate ion ($R-S^-$) then initiates another S_N2 reaction, replacing the opposite mesylate group, thereby yielding **B**.



Therefore, the answer is B.

11. **RM100,000**

To determine the current fair price of the lottery payments, we can use the formula for the present value of a growing perpetuity. The formula is as follows:

$$PV = \frac{C}{r - g}$$

where:

$$\begin{aligned} PV &= \text{Present Value} \\ C &= \text{First payment} \\ r &= \text{Discount rate (interest rate)} \\ g &= \text{Growth rate of the payments} \end{aligned}$$

Given:

- The first payment, C = RM2000
- The growth rate, g = 3% = 0.03
- The discount rate, r = 5% = 0.05

Inserting these values into the formula, we get:

$$PV = \frac{2000}{0.05 - 0.03} = \frac{2000}{0.02} = 100000$$

Hence, the current fair price of these payments is $\boxed{\text{RM100,000}}$.

12. (i) **Red:** $\boxed{\textbf{Regulus, Leo}}$
Blue: $\boxed{\textbf{Capella, Auriga}}$

(ii) $\boxed{\textbf{Segment 4, Sirius, Canis Majoris}}$

(iii) $\boxed{\textbf{45}^\circ \textbf{ North}}$
The latitude of an observer can be found by measuring the altitude (angle from the horizon) of the North Celestial Pole (NCP). Because Polaris is so close to the NCP, it's generally taken to be the Pole Star.

From the diagram, Polaris by itself is hard to find. However, the Big Dipper is widely recognised and easy to spot (in segment 11). By extending the line connecting the 2 stars in the Big Dipper closest to the centre, we can find Polaris as the bright star along that line.

Since Polaris sits halfway across the line from the edge to the centre, its altitude is $0.5 \times 90^\circ = \boxed{45^\circ}$. Also, it can be directly inferred that the group is in the $\boxed{\text{Northern hemisphere}}$, because if they were in the Southern hemisphere, they couldn't have seen Polaris in the first place.

References

Section A: Beach

1. The image in **Q6** is sourced from:
   Western Australian Museum. Echinodermata (echinoderms) [Image on the internet]. Government of Western Australia; 2015 [cited 2025 Feb 3]. Available from: https://museum.wa.gov.au/research/collections/aquatic-zoology/marine-invertebrates-section/echinodermata-echinoderms

2. **Q9** and **its solution** are adapted from:
   Hudson D. UKCLO Round 1 2012 [Internet]. United Kingdom Linguistics Olympiad (UKLO); 2014 [cited 2025 Feb 21]. Available from: https://www.uklo.org/wp-content/uploads/2022/09/2012.3w-Welsh.pdf