



## Youth STEM Cup 2025

Preliminary Round  
(Senior Category)

Problems and Answers

19 April 2025

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# Committee and Contributions

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## Organising Committee

Organisers of the Youth STEM Cup 2025:

<i>Advisor</i>	<i>Secretary</i>	<i>Logistics</i>
Liew Ze Wei	Goh Chung Wei	Phuah Jun Xi
	Tan Wei Zheng	Thura Linn Htet
<i>Event coordinator</i>		Ian Harris
Ashwin Asokan	<i>Head of PSC</i>	Aisyah Zuelaika
Adam Zachry	Tan Yong Zen	April Phuan
Tan Hong Zher		
Yahaya bin Basiron	<i>Publicity</i>	<i>Sponsorships and External Relations</i>
Aaron Oong Zhu Wen	Lee Jun Xuan	Bon Hao Yin
	Leang Kar Men	Hessa Assila
<i>Treasurer</i>	Swetha Rao	Felix Wong
Ang Eng Sheng	Loh Jing Chen	Joey Ding Jie Yi
	Yong Kah Yi	Nicholas Peh Yu Jie
		Chung Jia Chi

## Problem Selection Committee

The Problem Selection Committee (PSC) is responsible for setting and selecting problems for the contest. It makes collaborative decisions on the suitability and format of the questions, and performs cross-checks to ensure the questions are valid, clear, and well-posed. It also produces the *Problems and Answers* document, the *Solutions* document and the question paper.

Special thanks to the PSC for contributing 36 problem proposals for the Preliminary Round:

<i>Biology</i>	<i>Mathematics</i>
Tan Yong Zen, Tan Hong Zher, Ms Ong Sy Ing (Kolej PERMATA@Pintar Negara UKM), Dr Diana Atiqah binti Zainal Abidin (Program ASASIpintar UKM)	Leen Jun Khye, Chuah Jia Herng, Leia Mayssa
<i>Chemistry</i>	<i>Planetary Science</i>
Ng Ze Xian, Joyton Fu Hung Li, Aaron Oong Zhu Wen	Cheong Kar Hin, Lucas Cheah Hoe Yeen, Yahaya bin Basiron, Loh Jing Chen
<i>Physics</i>	<i>Social Science</i>
Adam Zachry, Tan Hong Zher, Teo Jia Quan	Shee Yi Rong, Quincy Jules Tan Yi Liing, Lim Ming Wen, Tan Hong Zher

# Preliminary Round Analysis

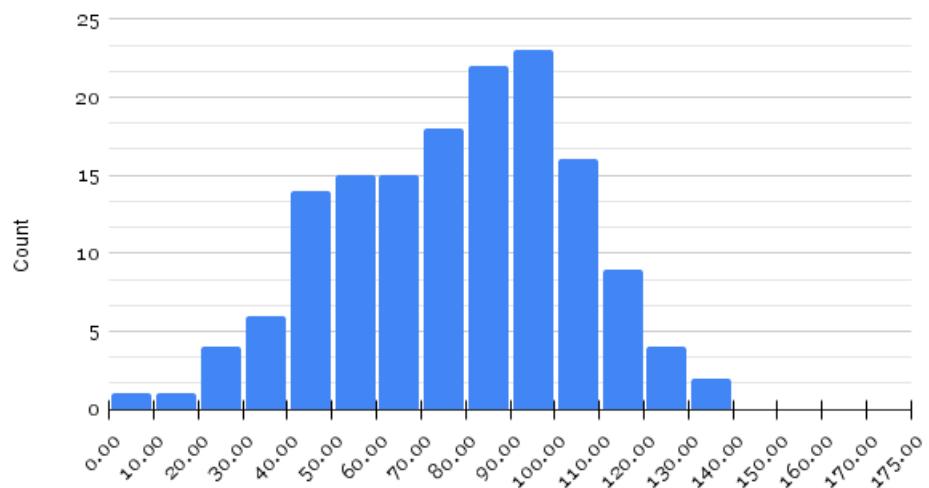
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## General Statistics

Duration	60 minutes
Full Score	175
Total Number of Responses (Individual participants + Teams)	150
Average Score	77.33
Median Score	80
Range	4 – 133
Standard Deviation	25.6

## Score Distribution

Histogram of Scores (Senior)



## Breakdown of Correct Responses

Bio		Chem		Phy		Maths		Planetary		Social	
Q	Freq	Q	Freq	Q	Freq	Q	Freq	Q	Freq	Q	Freq
1	117	1	97	1	77	1	41	1	92	1	87
2	85	2	95	2	72	2	36	2	81	2	40
3	98	3	96	3	38	3	Bonus	3	84	3	42
4	103	4	77	4	42	4	67	4	88	4	22
5	111	5	58	5	67	5	48	5	71	5	43
6	103	6	63	6	23	6	46	6	29	6	18
$\Sigma$	617	$\Sigma$	486	$\Sigma$	319	$\Sigma$	238	$\Sigma$	445	$\Sigma$	252

# Problems

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## Biology

Questions 1 and 2 are based on the following passage.

Photorespiration is a process that occurs in photosynthesising plant cells. It occurs due to rubisco's relatively high affinity for oxygen compared to carbon dioxide. As a result, oxygen is fixed onto RuBP instead of carbon dioxide, forming a 5-carbon molecule instead of a 6-carbon molecule. The product splits, and a 2-carbon compound leaves the chloroplast, where it is then rearranged to form carbon dioxide which can then be used in the Calvin cycle.

This process is energetically costly, and can prove detrimental for the photosynthesising plant. This is because ATP is spent, and organic material from the Calvin cycle is siphoned out for photorespiration to occur, decreasing the photosynthetic output!

1. There are some photosynthetic adaptations to overcome the downsides of photorespiration in C<sub>4</sub> and CAM plants. Based on your overall understanding of photosynthesis, which of the following is a possible unique adaptation of these plants? 4 marks
  - A. The plants restrict entry of oxygen into the leaf during photosynthesis.
  - B. The plants accumulate carbon dioxide at the site of the Calvin cycle.
  - C. The plants contain hydrolytic enzymes which degrade the enzyme that has affinity for oxygen.
  - D. The plants use the oxygen as a final electron acceptor at the ETC of the mitochondria.
2. Read the information below as well.

Most plants are C<sub>3</sub> plants. C<sub>3</sub> plants are aptly named because the first organic product formed after carbon fixation is a **three**-carbon product, formed after the CO<sub>2</sub> is fixed onto RuBP.

Based on the nomenclature (naming convention) of C<sub>4</sub> and CAM plants, which of the following could be a possible mechanism of the plants respectively? 6 marks

**Hint:** CAM stands for Crassulacean Acid Metabolism!

	C <sub>4</sub> plants	CAM plants
A.	The plant contains the PEP carboxylase, which fixes two CO <sub>2</sub> molecules to a three-carbon compound PEP.	The plant fixes CO <sub>2</sub> to various organic acids at night while its stomata are open, and this CO <sub>2</sub> can be used during the day for the Calvin cycle while the stomata are closed.

B.	The plant's rubisco enzyme is modified to be capable of affixing three carbon dioxide molecules to each RuBP.	The plant produces acids capable of reacting with oxygen, preventing it from binding to the rubisco enzyme.
C.	The plant contains the PEP carboxylase, which fixes a CO <sub>2</sub> molecule to a three-carbon compound PEP.	The plants synthesise acids which replace NADP <sup>+</sup> as the final electron acceptor in non-cyclic photophosphorylation.
D.	Spatial separation occurs in this plant, where CO <sub>2</sub> is affixed in the mesophyll cell and transported to the neighbouring bundle sheath cells.	Temporal separation occurs in this plant, where CO <sub>2</sub> is only taken up at night to be affixed to various organic acids and used in the day for the Calvin cycle.

3. Since its proposal in the 1960s, the molecular clock has become an essential tool in many areas of evolutionary biology, including systematics, molecular ecology, and conservation genetics. The molecular clock hypothesis states that DNA and protein sequences evolve at a rate that is relatively constant over time and among different organisms. In molecular clock studies, what is the main reason for using nuclear DNA instead of mitochondrial DNA for estimating divergence times in certain groups of organisms? 5 marks

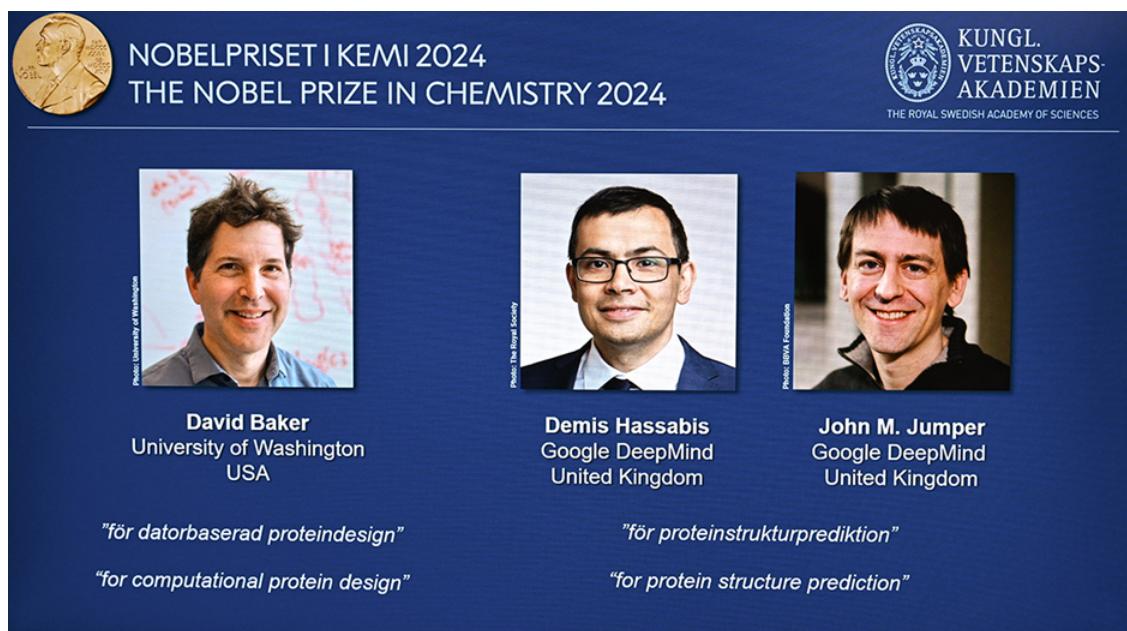
- A. Nuclear DNA has a higher mutation rate than mitochondrial DNA.
- B. Nuclear DNA is less prone to horizontal gene transfer.
- C. Mitochondrial DNA evolves too slowly to provide accurate estimates for deep divergences.
- D. Mitochondrial DNA is inherited maternally, which can result in biases in certain phylogenetic studies.

4. Skeletal muscle energy metabolism involves converting nutrients into chemical energy (ATP) through various pathways. The continual supply of ATP to the fundamental cellular processes that underpin skeletal muscle contraction during exercise is essential for sports performance in events lasting seconds to several hours. Because the muscle stores of ATP are small, metabolic pathways must be activated to maintain the required rates of ATP resynthesis. During intense exercise, which energy system is primarily responsible for the initial rapid ATP production? 6 marks

- A. Anaerobic glycolysis
- B. Creatine phosphate system
- C. Oxidative phosphorylation
- D.  $\beta$ -oxidation of fatty acids

5. In the realm of science, there are constant breakthroughs that push the boundaries of what we know about biology, chemistry, and biochemistry. One of the most significant recent advancements is the Nobel Prize in Chemistry for 2024. It was awarded to David Baker “for computational protein design”, while Demis Hassabis and John M. Jumper received the prize “for protein structure prediction”. This prize was awarded for a groundbreaking discovery in biochemistry that has the potential to revolutionize the way we understand biological processes at the molecular level. The research focuses on “protein modifications” and how these molecular changes influence various biological systems.

The research centers on the discovery of how the addition of small molecules to proteins, known as post-translational modifications (PTMs), influences their function and how these changes can control processes like cell signaling, gene expression, and immune response. The discoveries provide insight into how cellular processes, such as how cells adapt to environmental changes, develop resistance to diseases, and regulate normal bodily functions. This knowledge also lays the foundation for targeted therapies, offering hope for the development of more effective treatments for various diseases, including cancer and neurodegenerative conditions.



In the context of biochemistry, why is the ability to predict protein structures from amino acid sequences so important? 4 marks

- A. It enables the synthesis of proteins without the need for cellular machinery, reducing the cost of biotechnological processes.
- B. It helps researchers understand how the sequence of amino acids determines the protein's three-dimensional structure, which directly influences its function.
- C. It allows scientists to eliminate the need for experimental methods like X-ray crystallography or NMR spectroscopy.
- D. It enables the identification of genes responsible for diseases by predicting their amino acid sequences.

6. Read the following passage and answer the following question.

Cellular respiration is said to be incredibly efficient in its energy conversion, having an efficiency of **34%**. The remaining energy stored in glucose is lost by the body in the form of heat. This allows humans to maintain their relatively high body temperature.

Some hibernating mammals have a channel protein known as an **uncoupling protein** found on the inner membrane of the mitochondria in cells of a tissue known as brown fat, allowing proton movement across the inner membrane.

Based on your knowledge of chemiosmosis in the mitochondria, which of the following is a possible side effect of the presence of the uncoupling protein, and what is a possible advantage of this evolutionary adaptation?

**5 marks**

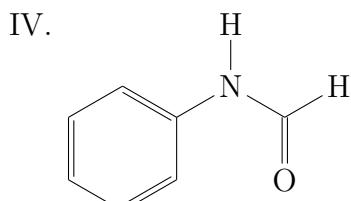
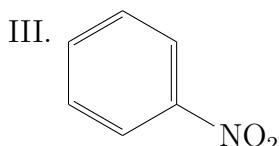
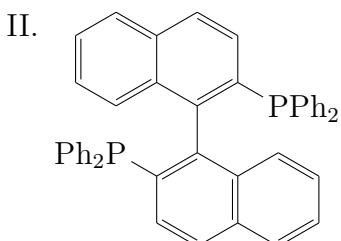
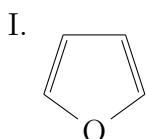
- A. The protein complexes in the electron transport chain would be rendered inefficient, reducing the number of protons that are pumped into the intermembrane space.
- B. Protons would stop being pumped into the intermembrane space of the mitochondrion, and this prevents excessive buildup of protons in the intermembrane space, which would cause a sharp drop in pH.
- C. ATP production would be limited, ensuring the cellular respiration of the brown fat tissue can continue throughout the hibernation period.
- D. The pH of the mitochondrial matrix will sharply increase, due to the regeneration of both NADH and FADH<sub>2</sub>.

# Chemistry

1. What is the pH of 0.888 M NaHTeO<sub>4</sub> and 0.666 M KHCO<sub>3</sub> respectively? 4 marks  
(For H<sub>2</sub>TeO<sub>4</sub>, pK<sub>a1</sub> = 7.68, pK<sub>a2</sub> = 11.00; For H<sub>2</sub>CO<sub>3</sub>, pK<sub>a1</sub> = 6.35, pK<sub>a2</sub> = 10.33)

- A. 9.34, 8.34
- B. 9.00, 8.68
- C. 5.53, 5.25
- D. 5.19, 5.58

2. Which species has a planar geometry? 4 marks



- A. I, II and III only
  - B. II, III and IV only
  - C. I, III and IV only
  - D. All of the above
3. An electrochemical approach to directly capture carbon dioxide and convert it to methanol has been introduced as an effort to achieve zero carbon emissions in 2050. The system uses water as anode and carbon dioxide (with catalyst) as cathode.

Assuming standard conditions and catalyst has no effect on the standard reduction potential, calculate the minimum voltage required to convert carbon dioxide to methanol based on the following thermodynamic data:

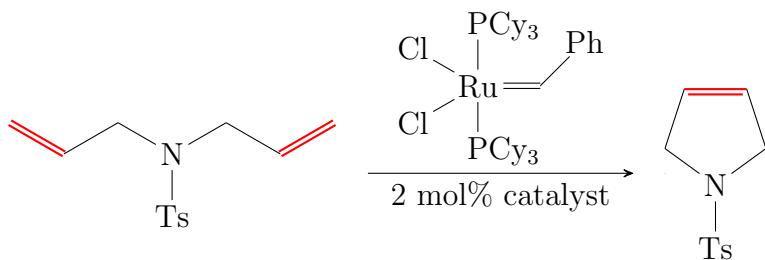
Compound	CO <sub>2</sub> (g)	H <sub>2</sub> O(l)	CH <sub>3</sub> OH(l)	O <sub>2</sub> (g)
$\Delta H_f^\circ$ (kJ mol <sup>-1</sup> )	-393.5	-285.8	-238.4	0
S° (J mol <sup>-1</sup> K <sup>-1</sup> )	213.8	70.0	127.2	205.2

**Note:** Faraday's constant = 96500 C/mol and **neglect** any effects on overpotentials.

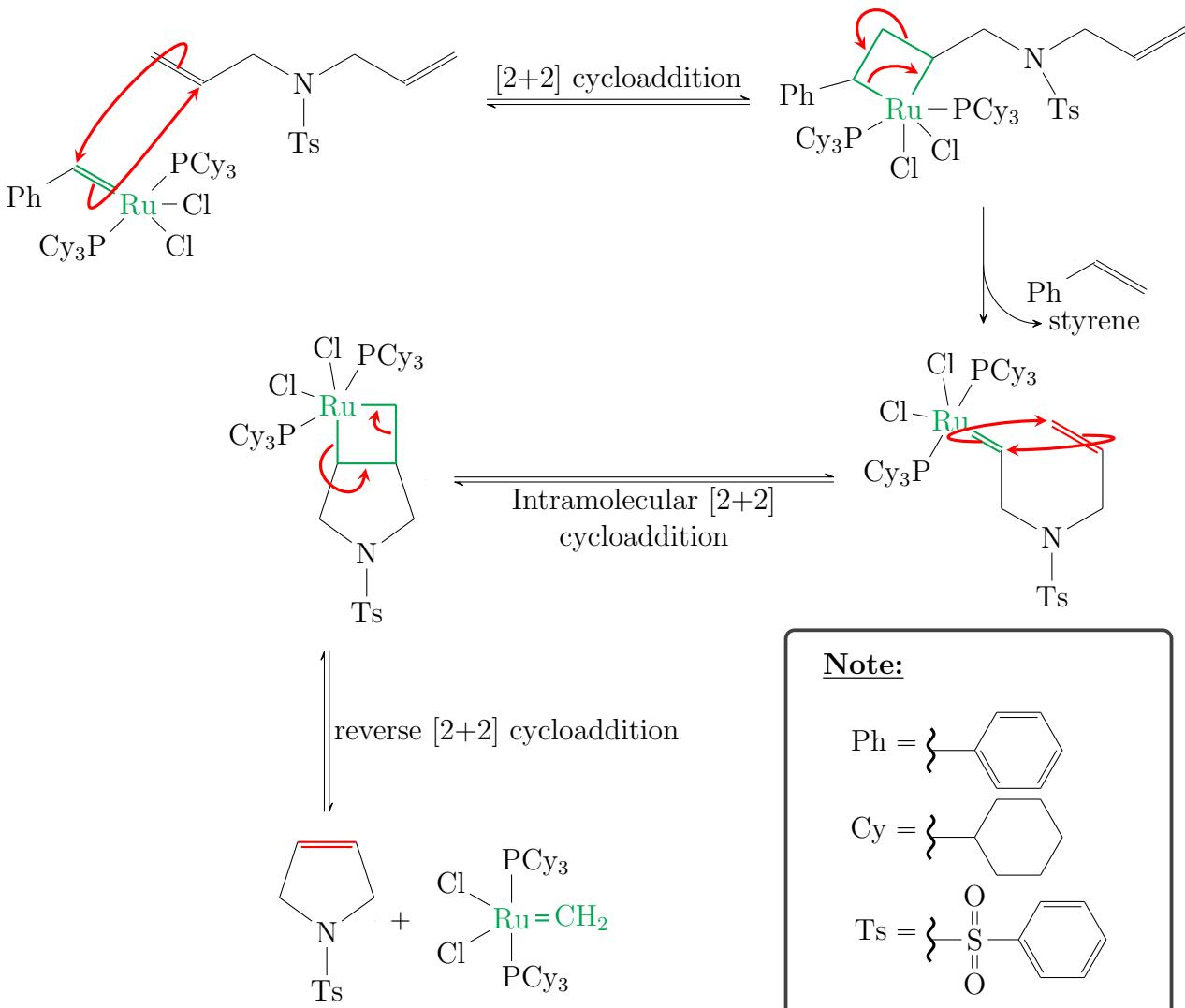
5 marks

- A. 0.95 V
- B. 1.21 V
- C. 1.61 V
- D. 1.82 V

4. One of the most common organometallic reactions is the alkene metathesis with Grubbs catalyst, making it one of the most powerful tools of organic synthesis. Consider this example:



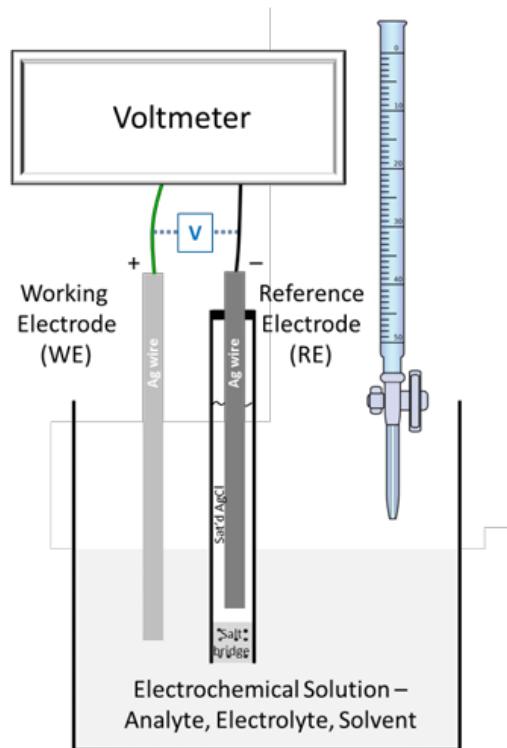
The mechanism of this reaction is as below:



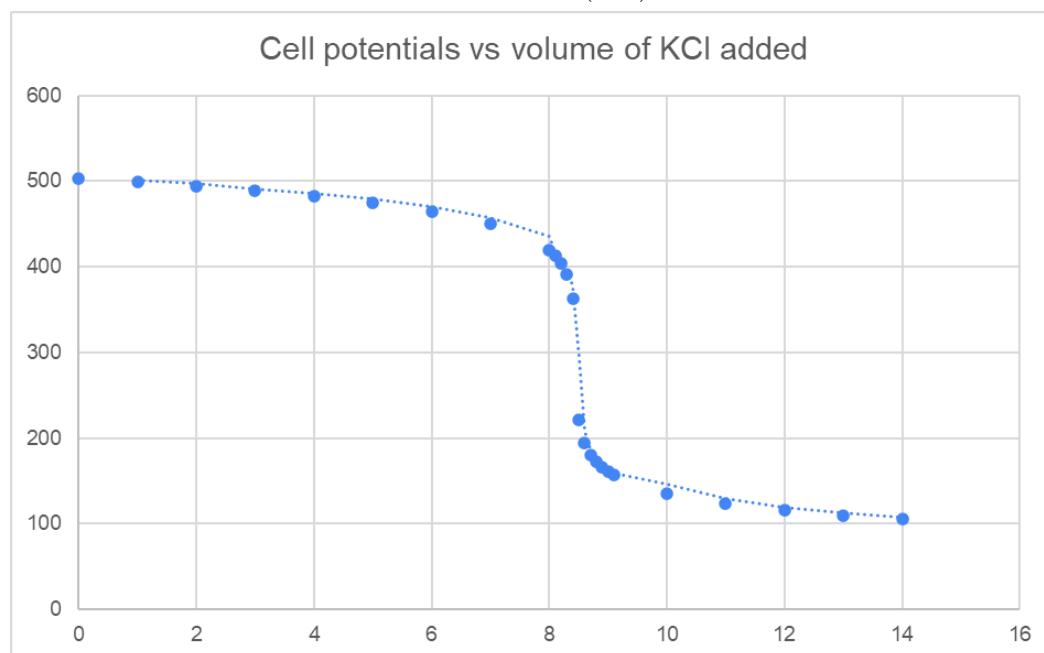
What are the possible side products if the equatorial organic ligand on the ruthenium complex is changed to ethylidene (=CHCH<sub>3</sub>) instead? [5 marks]

- I. Methane
  - II. Ethene
  - III. Propene
  - IV. Butene
- 
- A. I and II
  - B. II and III
  - C. I and III
  - D. I and IV

5. Potentiometric titration is a method that measures changes in electrode potential ( $E$ ) as a function of titrant volume, without relying on a visual indicator. In the titration of silver ions ( $\text{Ag}^+$ ) and chloride ions ( $\text{Cl}^-$ ), the typical electrode setup consists of a working electrode made of silver ( $\text{Ag}/\text{Ag}^+$ ) immersed in a standard  $\text{AgNO}_3$  solution, paired with a reference electrode made of silver and submerged in a saturated  $\text{AgCl}$  solution. This electrode pair detects changes in the free  $\text{Ag}^+$  concentration, as illustrated in the diagram below. The standard reduction potential of  $\text{Ag}^+/\text{Ag}$  is 0.80 V versus the standard hydrogen electrode (SHE).



In the example below, 20.0 mL of an  $\text{AgNO}_3$  solution with an unknown concentration is titrated against a 0.12 M KCl solution. The following graph shows the cell potential (mV) versus the volume of 0.12 M KCl solution added (mL).



What is the initial concentration of the  $\text{AgNO}_3$  solution and the  $K_{\text{sp}}$  of  $\text{AgCl}$  according to the potential curve obtained above?

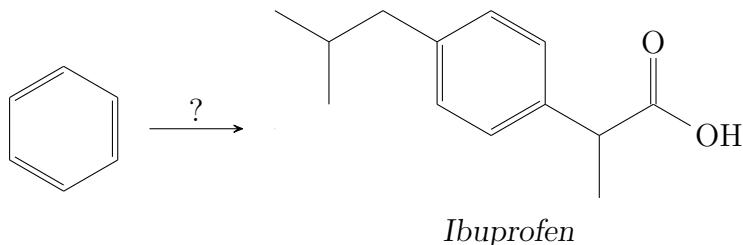
**Note:**

- Treat  $\frac{RT}{F} = 0.0592$  and
- Equivalence point as 8.35 mL with cell potential of 289 mV.

**6 marks**

	Initial concentration of $\text{AgNO}_3$ solution (M)	$K_{\text{sp}}$
A.	0.044	$1.3 \times 10^{-5}$
B.	0.050	$1.7 \times 10^{-10}$
C.	0.044	$5.48 \times 10^{-18}$
D.	0.050	$2.4 \times 10^{-11}$

6. The synthesis of ibuprofen can be started from benzene as depicted below.



Which of the following options shows the correct synthesis steps for ibuprofen? **6 marks**

- |  |   |   |                                  |  |                   |                             |
|--|---|---|----------------------------------|--|-------------------|-----------------------------|
| A. (1) $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{Cl}$ , $\text{AlCl}_3$ | (2) $\text{CO} + \text{HCl}$ , anhydrous $\text{AlCl}_3$                      | (3) $\text{LiAlH}_4$ , $\text{H}_2\text{O}$ | (4) $\text{HCl}$                 | (5) $\text{Mg}$ , Ether                | (6) $\text{CO}_2$ | (7) $\text{H}_2\text{SO}_4$ |
| C. (1) $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{Cl}$ , $\text{AlCl}_3$ | (2) $\text{CH}_3\text{COCl}$ , $\text{AlCl}_3$                                | (3) $\text{NaBH}_4$ , $\text{MeOH}$         | (4) $\text{NaCN}$ , $\text{HCN}$ | (5) $\text{Mg}$ , Ether                | (6) $\text{CO}_2$ | (7) $\text{H}_2\text{SO}_4$ |
| B. (1) $\text{CH}_3\text{COCl}$ , $\text{AlCl}_3$                                | (2) $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{Cl}$ , $\text{AlCl}_3$ | (3) $\text{NaBH}_4$ , $\text{MeOH}$         | (4) $\text{HBr}$                 | (5) $\text{Mg}$ , $\text{H}_2\text{O}$ | (6) $\text{CO}_2$ | (7) $\text{H}_2\text{SO}_4$ |
| D. (1) $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{Cl}$ , $\text{AlCl}_3$ | (2) $\text{CH}_3\text{COCl}$ , $\text{AlCl}_3$                                | (3) $\text{LiAlH}_4$ , Ether                | (4) $\text{HBr}$                 | (5) $\text{Mg}$ , Ether                | (6) $\text{CO}_2$ | (7) $\text{H}_2\text{SO}_4$ |

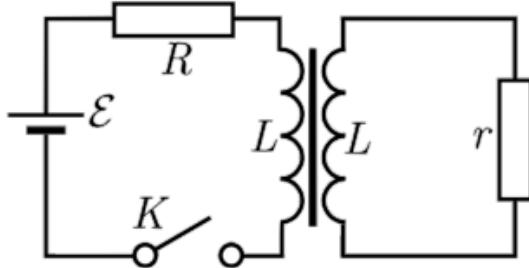
# Physics

1. While the Trinity Test was being held in New Mexico, Yong Zen made a ground-breaking discovery in plasma physics and had to urgently tell Oppenheimer. He kept his findings in a tube, and used a handheld cylindrical cannon of cross-sectional area,  $A$ , to shoot it towards Oppenheimer (don't ask why). When the cannon is fired, the tube is at rest, the volume between the end of the cylinder and the tube is  $V_0$ , and the pressure of the gas in this volume is  $P_0$ . The atmospheric pressure is  $P_{\text{atm}}$ , where  $P_0 > P_{\text{atm}}$ . The gas in the cylinder is diatomic; this means that  $C_V = \frac{5R}{2}$  and  $C_P = \frac{7R}{2}$ . The tube moves down the cylinder quickly enough that no heat is transferred to the gas. Friction between the tube and the barrel is negligible and no gas leaks around the tube. Find the maximum kinetic energy,  $E_{\text{max}}$ , so that the tube can exit the cannon.

**[6 marks]**

- A.  $E_{\text{max}} = V_0 \left( \frac{5}{2}P_0 + P_{\text{atm}} - \frac{7}{2}P_{\text{atm}}^{\frac{2}{7}}P_0^{\frac{5}{7}} \right)$       C.  $E_{\text{max}} = 2V_0(5P_0 + P_{\text{atm}} - 7P_{\text{atm}}^{\frac{2}{7}}P_0^{\frac{5}{7}})$   
 B.  $E_{\text{max}} = V_0(5P_0 + P_{\text{atm}} - 7P_{\text{atm}}^{\frac{2}{7}}P_0^{\frac{5}{7}})$       D.  $E_{\text{max}} = 4V_0(5P_0 + P_{\text{atm}} - 7P_{\text{atm}}^{\frac{2}{7}}P_0^{\frac{5}{7}})$

2. In the not-so-near future, Hong Zher is trying out a new transformer to help power Herriott-Watt University during the YSC 3025. He needs some help figuring out an expression for the current in both loops immediately after the switch is closed.



Both windings of the transformer have the same number of loops and the self-inductance of both coils is equal to  $L$ . There is no leakage of the magnetic field lines from the core, so that the mutual inductance is also equal to  $L$ .

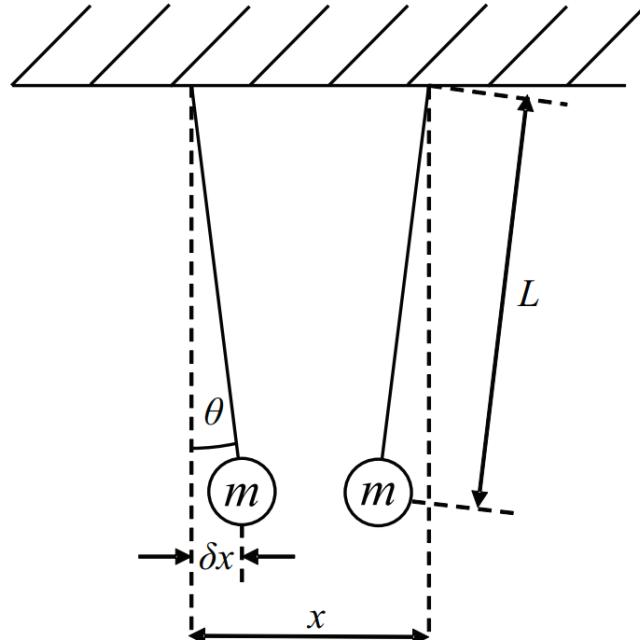
**[3 marks]**

- A.  $I = \frac{\epsilon(R+r)}{Rr}$       B.  $I = \frac{\epsilon}{R+r}$       C.  $I = \frac{\epsilon(R+r)}{R^2}$       D.  $I = \frac{\epsilon(R+r)}{r^2}$
3. A YSC 2025 participant, who is banished to the planet "CheatingDuringPrelims-ia" for using AI to help solve the prelim questions, travels to the top of a mountain overlooking the sea. The participant's eye is 1500 m above the sea level and he observes that the horizon in all directions appears to be at an angle of 8 mrad below the local horizontal. What is the radius of the planet "CheatingDuringPrelims-ia" at sea level?

**[3 marks]**

- A. 3124900 m      C. 3125900 m  
 B. 3250000 m      D. 3330000 m

4. As part of the YSEC 200 BC, Aaron was tasked to investigate two spheres of mass  $m$  suspended from wires of negligible mass. The length between the pivot points and the centres of each sphere is  $L$ . The two suspension points lie on a horizontal line and are separated by a distance  $x$ . The system is in equilibrium. Take the total acceleration due to gravity to be  $g$ .



Aaron wants to find the small deflection  $\delta x$  by which the gravitational force  $F_g$  between the spheres will deflect them from the vertical.

**6 marks**

**Hint:** You may assume that  $\delta x \ll L$  as well as  $\delta x \ll x$ .

A.  $\delta x = \frac{x}{2} - \sqrt{\frac{x^2}{4} - \frac{LMG}{xg}}$

C.  $\delta x = \frac{x}{8} - \sqrt{\frac{x^2}{64} - \frac{LMG}{xg}}$

B.  $\delta x = \frac{x}{8} - \sqrt{\frac{x^2}{64} - \frac{LMG}{4xg}}$

D.  $\delta x = \frac{x}{2} - \sqrt{\frac{x^2}{4} - \frac{LMG}{4xg}}$

5. Suppose the magnitude of a non-uniform gravitational field on a Cartesian plane is given by the equation  $g(x, y) = xy$ , and the direction pointing towards the  $x$ -axis. If a thin rod with non-uniform length density  $\rho(x, y) = x + y$  is placed on the plane with end coordinates  $(1, 1)$  and  $(2, 2)$ , calculate the distance between coordinates of the center of mass and the center of gravity of the rod.

**6 marks**

- A. 0.01
- B. 0.08
- C. 0.14
- D. 0.20

6. Three particles A, B and C are moving in the positive direction, with particle B between particles A and C. Particle A has velocity  $\frac{\alpha}{\gamma}c$ , particle B has velocity  $\beta c$ , while particle C has velocity  $\frac{\delta}{\gamma}c$ . If particle B sees particles A and C approaching it at the same speed, and  $(\alpha, \delta, \gamma)$  is a Pythagorean triple, express  $\beta$  in terms of  $\alpha$ ,  $\delta$ , and  $\gamma$ .

6 marks

**Note:**  $c$  refers to the speed of light, and all the variables are positive integers.

A.  $\beta = \frac{2\gamma}{\alpha + \beta}$

C.  $\beta = \frac{\alpha + \delta}{2\gamma}$

B.  $\beta = \frac{\alpha + \delta}{\gamma}$

D.  $\beta = \frac{\gamma}{\alpha + \delta}$

# Mathematics

1. The  $4 \times 4$  sliding puzzle consists of a grid containing the numbers 1 through 15 and one empty space. The objective is to arrange the numbers in ascending order from left to right, top to bottom, with the empty space placed at the bottom-right corner. Players can only move tiles that are adjacent to the empty space, sliding them vertically or horizontally into the empty spot (diagonal moves are not allowed). Each move must maintain the structure of the grid, and no tiles can be removed. The game is solved when all the numbers are in the correct order. How many of the following grids can be sorted in the correct order?

7	4	8	5
15	6	10	2
11	13	14	9
3	12	1	

7	4	8	5
1	14	10	2
11	13	6	9
3	12	15	

7	4	8	5
9	6	10	2
11	13	14	15
1	12	3	

5	4	8	7
15	6	10	2
11	13	14	9
1	12	3	

4 marks

- A. 1  
B. 2  
C. 3  
D. 4
2. Let  $a_i$  be positive integers such that

$$2025 = \binom{a_1}{2} + \dots + \binom{a_n}{2}$$

What is the smallest possible  $n$ ?

4 marks

- A. 2  
B. 3  
C. 4  
D. 1
3. A  $1 \times 2025$  strip is made up of 2025 unit squares. Ali chooses two distinct unit squares randomly and uniformly, what is the expected value of the distance between the centers of two chosen unit squares?
- 5 marks
- A. 1012  
B.  $\frac{2024}{3}$   
C. 506  
D.  $\frac{2026}{3}$
4. Suppose  $J$  is the  $A$ -excenter of  $\triangle ABC$  where  $AC = 21$ . Let the line through  $J$  parallel to  $AB$  cut segments  $AC$  and  $BC$  at  $P$  and  $Q$  respectively. If  $PQ = 4$  and  $CP = 9$ , what is the length of  $BC$ ?
- 5 marks
- A. 12  
B. 14  
C. 15  
D. 18

5. For any  $a \in \mathbb{R}_{>0}$ , define the function  $f(x) = |\log x|$ , and let  $m_a$  be the minimum value of  $f(x)$  on the interval  $[a, \infty)$ . Also, define the function  $g(x) = \sin \frac{\pi x}{2}$ , and let  $M_a$  be the maximum value of  $g(x)$  on  $[a, \infty)$ . Determine how many values of  $a$  satisfy

$$M_a - m_a = \frac{1}{2}$$

6 marks



$$\text{A. } \frac{1}{\sqrt{2}}$$

C.  $\frac{2}{\sqrt{2}}$

B.  $\frac{\sqrt{2}}{\sqrt{2}}$

D.  $\frac{4}{\sqrt{2}}$

# Planetary Science

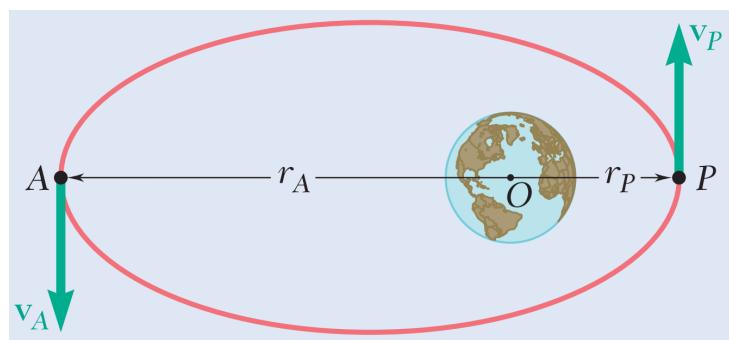
1. The following outcrop was found at Desaru. A sample was taken from this outcrop for analysis. (A 20 sen coin is used as a scale in the image below.)



Given the following properties, determine the type of depositional environment that it was formed in. 5 marks

- Creates a dull sound when hit with another sample from the same outcrop.
- The sample is brittle and can be easily scratched with a fingernail.
- Laminations were found on the surface of the rock.

- A. Shallow marine
  - B. Fluvial (rivers)
  - C. Lacustrine (lakes)
  - D. Aeolian (sand dunes)
2. The diagram shows the orbit of a satellite around Earth.  $M$  is the mass of Earth,  $m$  is the mass of the satellite and  $G$  is the gravitational constant.



Using the conservation of energy, or otherwise, express  $v_a$  in terms of  $G$ ,  $M$ ,  $r_a$  and  $r_p$ .

6 marks

Hint:

$$\bullet \frac{v_a}{v_p} = \frac{r_p}{r_a}$$

A.  $v_a = \sqrt{2GM \frac{r_p}{r_a(r_a + r_p)}}$

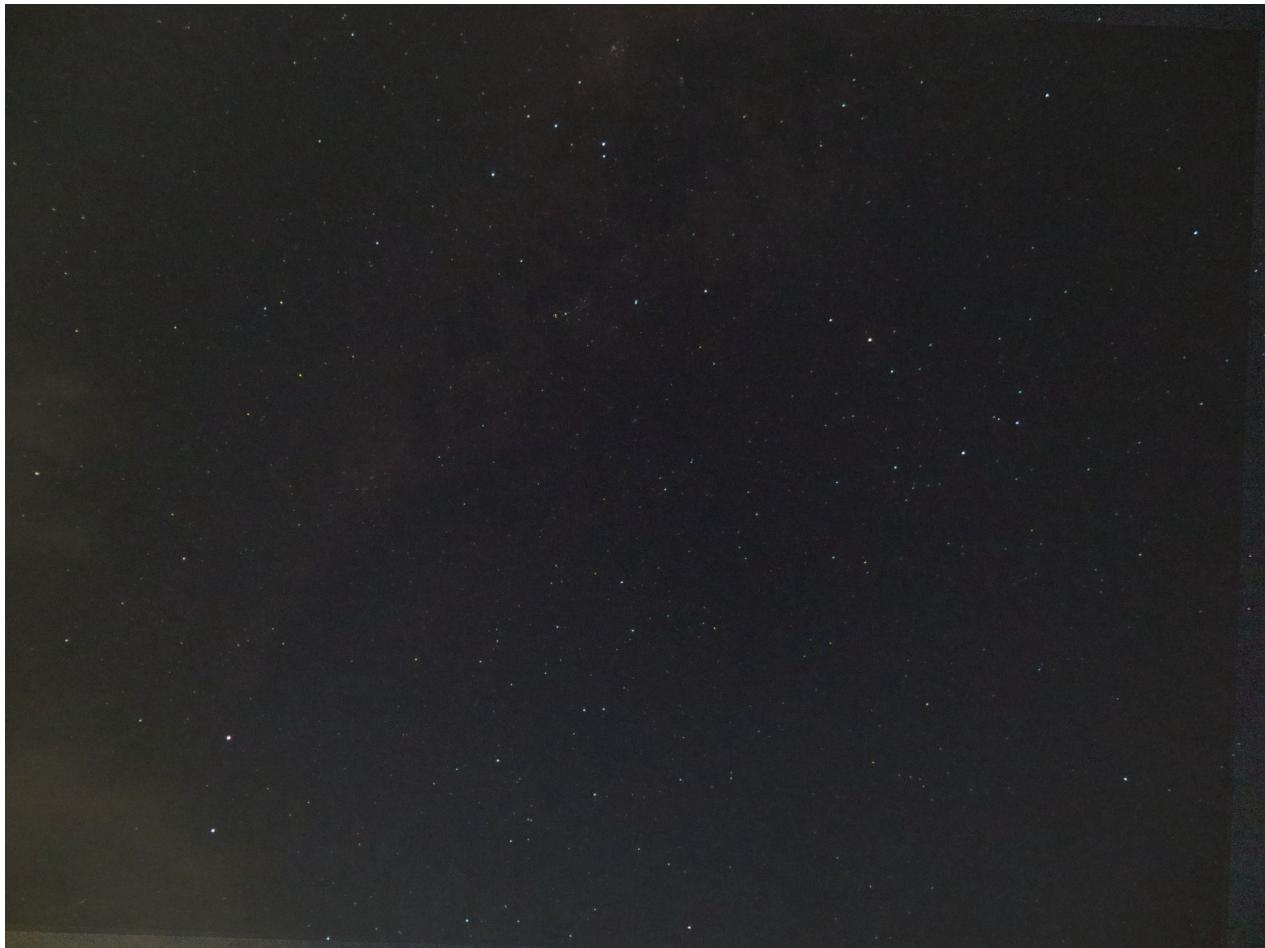
B.  $v_a = \sqrt{2GM \frac{r_p}{r_a(r_a - r_p)}}$

C.  $v_a = \sqrt{2GM \frac{r_a}{r_p(r_a + r_p)}}$

D.  $v_a = \sqrt{2GM \frac{r_a}{r_p(r_a - r_p)}}$

3. The following picture was taken in mid-August last year. Which of the following Messier objects CANNOT be seen in this picture?

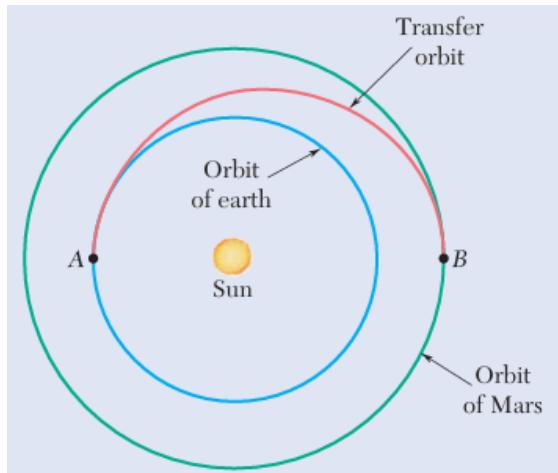
4 marks



- A. M6  
B. M2

- C. M4  
D. M7

4. Consider an energy-efficient Hohmann transfer orbit from Earth to Mars, which is an elliptical path around the Sun. The perihelion (closest point to the Sun) of this ellipse lies on Earth's orbit, while the aphelion (farthest point from the Sun) lies on Mars's orbit.



Assume both planets move in circular orbits. Earth's orbital radius  $a_{\oplus} = 1 \text{ AU} = 1.50 \times 10^8 \text{ km}$  and the Mars's orbital radius is  $a_{\text{Mars}} = 1.52 \text{ AU}$ . For a spacecraft transfer on Hohmann transfer orbit, calculate the time in years for the spacecraft to arrive at Mars. 6 marks

Given:

- Gravitational Constant,  $G = 6.674 \times 10^{11} \text{ Nm}^2/\text{kg}^2$
- Mass of Sun,  $M_{\odot} = 2 \times 10^{30} \text{ kg}$

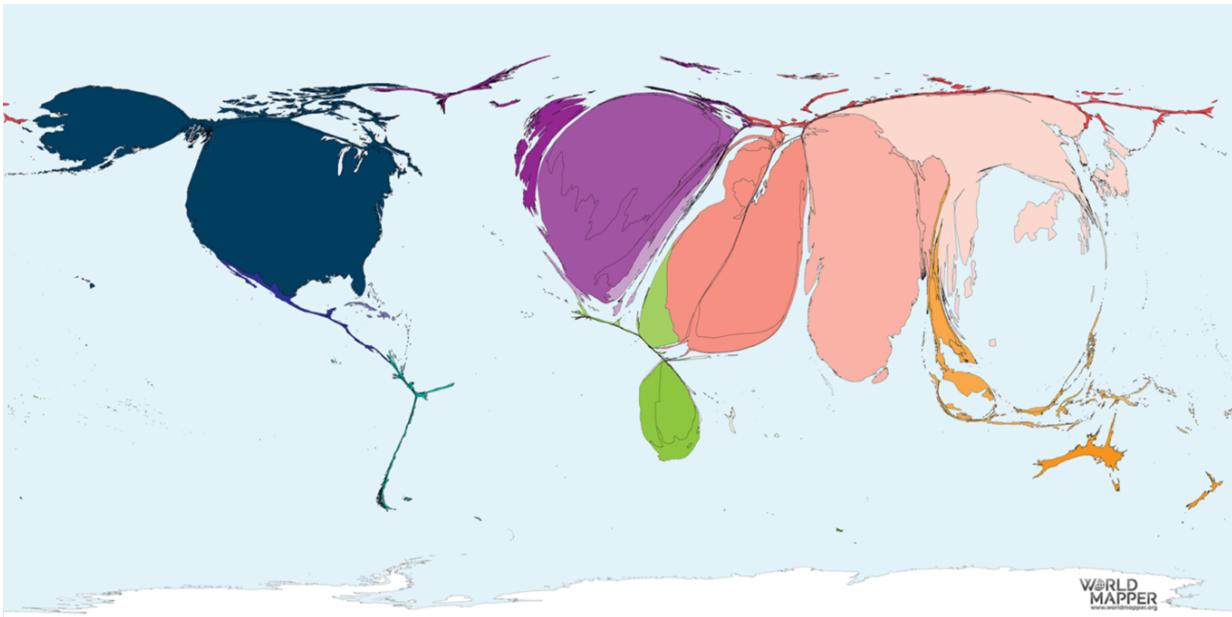
- A. 0.709 years  
 B. 1.064 years  
 C. 1.418 years  
 D. 2.127 years
5. Jing Chen is staying in City X, where the following celestial observations were made:
- All planets in the Solar System can be observed at different times of the year.
  - Betelgeuse (Declination =  $+7^{\circ}24'$ ) is never near the zenith in the sky.
  - Perseus Double Cluster (Declination =  $+57^{\circ}8'$ ) is circumpolar and never sets.
  - Large Magellanic Cloud (LMC) (Declination =  $-69^{\circ}45'$ ) is never visible.

Based on these observations, which of the following could be City X?

5 marks

- A. Colombo, Sri Lanka ( $7^{\circ} \text{ N}$ )  
 B. Hualian, Taiwan ( $24^{\circ} \text{ N}$ )  
 C. Sapporo, Japan ( $43^{\circ} \text{ N}$ )  
 D. Murmansk, Russia ( $69^{\circ} \text{ N}$ )

6. The map below is a cartogram, where countries are resized not according to their physical land area but based on their share in the global value or volume of a specific commodity. The distortion reflects each country's significance in the global trade or production of that item.



Based on the patterns shown, and given that the map was based on data in 2016, which of the following is most likely being represented?

**4 marks**

- A. Diamond Imports
- B. Potato Production
- C. Diamond Exports
- D. Rapeseed Production

## Social Science

1. Tony and Bob are playing a game. Tony has three cards with 2, 3 and 5 respectively written on them, whereas Bob has three cards with 3, 4, 6 respectively written on them. They will choose a card secretly and independently, and then show each other which card they chose.

If the sum of the numbers on the two cards is less than 6, Bob wins. If it is more than 9, Tony wins. If it is between (inclusive of) 6 to 9, the game is declared a draw.

Is there a strictly dominant strategy in this game?

3 marks

Definition:

Let Player 1 have strategy **a** and strategy **b**. We say that **a** strictly dominates **b** if, for every possible strategy profile of the other players, strategy **a** yields a payoff for Player 1 which is **greater than** the payoff associated with strategy **b**.

- A. Yes, Tony has a strictly dominant strategy.
  - B. Yes, Bob has a strictly dominant strategy.
  - C. No, neither of them have a strictly dominant strategy.
  - D. Both of them have strictly dominant strategies.
2. Countries often specialize in the production of certain goods due to endowment of resources (climate, land, human capital) specific to the country.

The country of Malatangisia specializes in producing egg tarts ( $E$ ) and charsiewbao ( $C$ ), and the production possibility frontier (or budget line equation) for this nation is  $E^2 + C^2 = 100$ . If the market prices of an egg tart and charsiewbao are RM5 and RM6 respectively, and the cost of producing either is RM2, which of the following statements is correct? [6 marks]

**Hint:** To find the maximum net profit, you must maximize revenue – cost subject to the constraints available.

- A. The cost of producing egg tarts are fixed.
  - B. The shape of the production possibility frontier (PPF) is a circle.
  - C. Malatangisia should specialize in charsiewbao production only to obtain the maximum net profit.
  - D. The net profit of producing egg tarts and charsiewbao is at most RM50.
3. Governments are concerned about behavioral biases, which are suboptimal decisions a consumer makes. For example, choosing between fast or healthy food, or loss aversion, where a consumer perceives a monetary loss to be worse than an equivalent gain.

One of the largest behavioral biases governments are trying to solve is the problem of undersaving. Often, consumers do not save when they are young, only to regret it in old age when they do not have savings to tide them over post-retirement. This is a behavioral bias known as time inconsistency.

The utility function of an undersaving individual when she is young can be described as:  $u(c_1, c_2) = c_1^\beta c_2^{(1-\beta)}$ , where  $c_1$  and  $c_2$  denote consumption in period 1 (young) and period 2 (old) respectively. (These are called **Cobb-Douglas preferences!**) She can also save some of her income,  $y_1$ , when she is young, to add to her income,  $y_2$ , when she is old. This is done with an interest rate of  $r$  (saving RM1 gives an additional income of RM $(1+r)$  at old age).

As she grows older, her utility function changes to become  $u(c_1, c_2) = c_1^{(1-\alpha)} c_2^\alpha$ . This is because she has retired and realizes she would have preferred her young self to save more. The present value of her lifetime income is  $y_1 + \frac{y_2}{1+r}$  because we discount her old-age income by the interest rate. Her budget constraint in period 1 is therefore  $c_1 + \frac{c_2}{1+r} \leq y_1 + \frac{y_2}{1+r}$ .

Because she is behaviorally biased, what is her consumption in period 2? What would herself in old age have preferred to consume in period 2? What would be a behavioral solution the government could employ to encourage her to save more?

**[6 marks]**

Use  $\alpha$  and  $\beta$  according to the values below:

$$\alpha = \sum_{x=-2}^3 (2x - 0.9)$$

$$\beta = 0.4 \text{ times the last digit of } 1962^{2003} \times 2003^{1962}$$

Hint:

A consumer consumes up until the marginal utility = 0.

- A.  $0.2(y_2(1+r) + y_1)$ ;  $0.6(y_2(1+r) + y_1)$ ; raising the interest rate to increase the return on savings.
  - B.  $0.2(y_2(1+r) + y_1)$ ;  $0.6(y_2(1+r) + y_1)$ ; automatic enrollment into pension schemes.
  - C.  $0.2(y_1(1+r) + y_2)$ ;  $0.6(y_1(1+r) + y_2)$ ; raising the interest rate to increase the return on savings.
  - D.  $0.2(y_1(1+r) + y_2)$ ;  $0.6(y_1(1+r) + y_2)$ ; automatic enrollment into pension schemes.
4. Animal ethics has always been a hot topic for philosophers. In which of the following four quotes does the writer **not** argue for animal rights and/or animal welfare?

**[5 marks]**

- A. “What could be the basis of our having more inherent value than animals? Their lack of reason, or autonomy, or intellect? Only if we are willing to make the same judgment in the case of humans who are similarly deficient. But it is not true that such humans—the retarded child, for example, or the mentally deranged—have less inherent value than you or I. Neither, then, can we rationally sustain the view that animals like them in being the experiencing subjects of a life have less inherent value. All who have inherent value have it equally, whether they be human animals or not.”

- B. “...if—tragically—there were two people drowning, and we could only save one of them... there would be strong moral reason to save the one, and equally strong moral reason to save the other... Given all of this, perhaps we should flip a coin to determine which person we save... in the case we are actually considering... we have, instead, one person and one mouse. But given the truth of utilitarianism, it seems, where people have no higher a moral status than mice do... this means that here too we should flip a coin to determine who to save. And if it turns out that the mouse is favored by the coin toss, then saving the mouse, rather than the person, is the morally right thing to do... Despite what we might initially think, then, there is no more reason to save the person than the mouse.”
- C. “Chimps and other great apes clearly possess an autobiographical self, as they are able to prepare themselves for future actions... they likely can, just as humans, be in pain over an anticipated future event that has yet to occur. For instance, confining someone in a prison or cage for a set time, or for life, would lose much of its power as punishment if that individual had no self-concept. Every moment would be a new moment with no conscious relation to the next. But, chimpanzees and other great apes have a concept of their personal past and future and therefore suffer the pain of not being able to fulfill one’s goals or move around as one wants; like humans they experience the pain of anticipating a never-ending situation.”
- D. “Many feminists hold that women have the right to an abortion on request. It does not follow that since these same feminists are campaigning for equality between men and women they must support the right of men to have abortions too. Since a man cannot have an abortion, it is meaningless to talk of his right to have one. Since dogs can’t vote, it is meaningless to talk of their right to vote... The extension of the basic principle of equality from one group to another does not imply that we must treat both groups in exactly the same way, or grant exactly the same rights to both groups. Whether we should do so will depend on the nature of the members of the two groups. The basic principle of equality does not require equal or identical treatment; it requires equal consideration. Equal consideration for different beings may lead to different treatment and different rights.”

For Questions 5 and 6, refer to the information below.

Long ago, there existed two kingdoms, Lingusitica and Olympicia. Not much is known about Lingusitica, but it is known that its people spoke the language of Linga. The people of Olympicia worshipped Kahin, the god of flight and spoke the language of Olima.

One day, archeologists stumbled upon a tablet, containing a few phrases in Linga and Olima. They were successfully translated into English, as below:

Linga	Olima	English
Le wek pas ou voro.	La blime un el polaw.	A bird and an axe.
Ba apal pas alp qena.	Ein loico un el elapnga.	An apple and the doctor.
Une gola pas pao patnne.	Opa layuti un ep glennga.	One table and two bats.
Man apal ni pao voromo.	Ein elap wo eop polawti.	The apple or two axes.
Lap katnne pas op trik.	El broon un eret piktinga.	Three cats and a wife.
Pao androsnne pas une vin.	Opa movakti un ep zam.	Two butterflies and one pear.
Pao trikmo pas lap vorpanne.	Reta ralomiti un eop broointinga.	Two wives and three pelicans.
Op mix ni le kat.	La vor wo el pik.	A kite or a cat.
Le vin pas pao quilnne.	Opa xilti un el zamnga.	A pear and two houseflies.
Lap alhodnne ni le andros.	La movak wo eret tovuptinga	Three trees or a butterfly.

**Note:**

In this question, bat refers to the flying mammal.

**Hint:**

Try to categorise the different nouns!

5. Which of the following translations from English to Linga is correct?

4 marks

- A. The pelican and two kites. - Alp vorpa pas pao mixmo.
- B. Two doctors or the butterfly. - Pao qenamo ni man andros.
- C. Three tables or a housefly. - Lap gola ni le quil.
- D. An axe and the wife. - Ou voro pas man trik.

6. Which of the following translations from English to Olima is correct?

6 marks

- A. Three kites or two pears. - Eop zamti wo eret vortinga.
- B. The axe and a bat. - La layu un ein polaw.
- C. Three doctors and the housefly. - Ina xil un eret loicotinga.
- D. The tree or the wife. - Ein tovup wo ein broonnga.

# Answers

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## Biology

1. B
2. D
3. D
4. B
5. B
6. C

## Mathematics

1. B
2. A
3. Omitted (D)
4. B
5. C
6. B

## Chemistry

1. A
2. C
3. B
4. B
5. B
6. D

## Planetary Science

1. C
2. A
3. B
4. A
5. C
6. A

## Physics

1. A
2. B
3. A
4. B
5. C
6. D

## Social Science

1. C
2. D
3. D
4. B
5. B
6. C

# References

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## Biology

1. **Q1, Q2 and Q6** are adapted from:  
Campbell NA, Cain ML, Minorsky PV, Orr RB, Urry LA, Wasserman SA. Biology: A Global Approach. Harlow (GB): Pearson Education Limited; 2021.
2. The image in **Q5** is sourced from:  
Offord C. Protein designer and structure solvers win chemistry Nobel [Image on the Internet]. 2024 [cited 2025 Apr 19]. Available from: <https://www.science.org/content/article/protein-designer-and-structure-solvers-win-chemistry-nobel>

## Chemistry

1. The images in **Q5** are sourced from:  
National University of Singapore (NUS) Department of Chemistry. CM2143: Equivalency Testing of Potentiometric Titration vs. Indicator Titration for the Determination of Silver Ion Concentration.

## Physics

1. **Q1** is adapted from Question A4 of:  
American Association of Physics Teachers (AAPT), American Institute of Physics (AIP). USAPhO 2009 Semi final Exam. c2009 [cited 2025 Apr 19]. Available from: <https://www.aapt.org/physicsteam/2019/upload/USAPhO-2009-Solutions.pdf>
2. **Q2** is adapted from Problem 5 of:  
Zhou K. Electromagnetism VI: Circuits [Internet]. [place unknown: publisher unknown]. Available from: <https://knzhou.github.io/handouts/E6Sol.pdf>
3. **Q4** is adapted from Question 18 of:  
University of Oxford Department of Physics. Physics Admission Test (PAT) 2018. 2018 [cited 2025 Apr 19]. Available from: [https://www.physics.ox.ac.uk/system/files/file\\_attachments/pat-2018.pdf](https://www.physics.ox.ac.uk/system/files/file_attachments/pat-2018.pdf)

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1. The images in **Q2** and **Q4** are sourced from:  
Beer FP, Johnston ER, Mazurek DF, Cornwell PJ, Self BP. Vector Mechanics for Engineers. Statics and Dynamics. New York (NY): McGraw Hill Education; 2024.
2. The image in **Q6** is sourced from:  
Worldmapper. Data Page: Diamond Imports [Image on the internet]. 2018 [cited 2025 Apr 19]. Available from: [Image-https://worldmapper.org/maps/diamond-imports-2016/](https://worldmapper.org/maps/diamond-imports-2016/)

## Social Science

1. The quote in **option A of Q4** is sourced from:  
Regan T. The Case for Animal Rights. Berkeley (CA): University of California Press; 2023.
2. The quote in **option B of Q4** is sourced from:  
Kagan S. How to Count Animals: More or Less. Oxford University Press; 2019.
3. The quote in **option C of Q4** is sourced from:  
Affidavit of Mathias Osvath sworn to November 19, 2013. Available from: <https://www.no-nhumanrights.org/wp-content/uploads/Suffolk-Ex.-11-Osvath-Affidavit-to-VP.pdf>
4. The quote in **option D of Q4** is sourced from:  
Singer P. Animal Liberation. The Bodley Head; 2015.