



# Youth STEM Cup 2024

(Junior Category)

Final Round

Problems and Answers

22 June 2024

In collaboration with



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# Committee and Contributions

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## Organising Committee

Organisers of the Youth STEM Cup 2024:

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Liew Ze Wei	<i>Secretary</i>	<i>Treasurer</i>
Lee Ke Yin	Ng Kin Him	Bok Zhe Shing
Joel Pang Kai Chen	Tan Zhi Qi	
	Yahaya bin Basiron	<i>Head of PSC</i>
		Aaron Oong Zhu Wen

## 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 *Problems and Solutions* document and the question paper.

Special thanks to the PSC for contributing 19 problem proposals for the Final Round:

<i>Biology</i>	<i>Mathematics</i>
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# Final Round Analysis

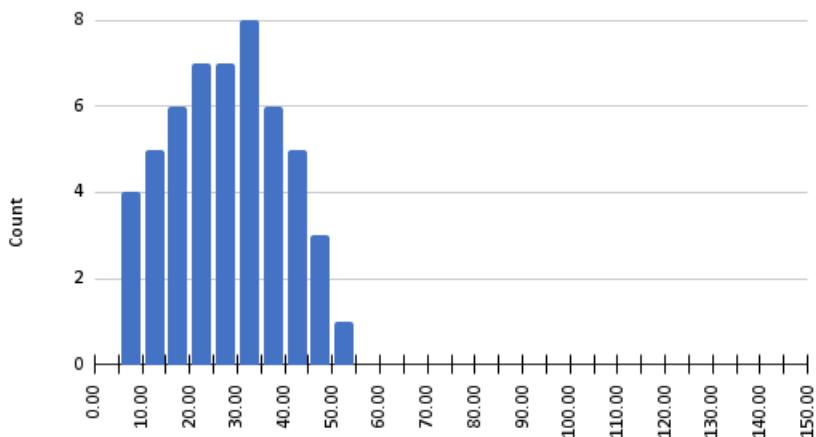
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## General Statistics

Duration	120 minutes
Full Score	150
Number of Teams	52
Average Score	28.01
Median Score	27.50
Range	7 – 52
Standard Deviation	11.78

## Score Distribution

Histogram of Score (Juniors)



## Breakdown of Responses

Bio			
Section	Question	Total Score per Question	Range of Scores obtained by participants
A	1	4	0 – 4
B	2	6	0 – 6
C	–	–	–
D	–	–	–
E	1	4	0 – 4
F	–	–	–

Chem			
Section	Question	Total Score per Question	Range of Scores obtained by participants
A	2	7	0 – 7
B	3	5.5	0 – 5.5
C	1	13	0 – 5
D	–	–	–
E	–	–	–
F	–	–	–

Phy			
Section	Question	Total Score per Question	Range of Scores obtained by participants
A	6	6	0 – 1.5
B	4	7	0 – 2.5
C	–	–	–
D	–	–	–
E	–	–	–
F	–	–	–

Maths			
Section	Question	Total Score per Question	Range of Scores obtained by participants
A	5	5	0 – 5
B	–	–	–
C	2	3	0 – 3
D	3	6	0 – 6
E	–	–	–
F	–	–	–

Earth			
Section	Question	Total Score per Question	Range of Scores obtained by participants
A	4	15	0 – 9
B	1	8	0 – 5.5
C	–	–	–
D	–	–	–
E	–	–	–
F	1	6	0 – 6

Social			
Section	Question	Total Score per Question	Range of Scores obtained by participants
A	3 & 7	34	0 – 13
B	–	–	–
C	–	–	–
D	1 & 2	20.5	0 – 15.5
E	–	–	–
F	–	–	–

# Problems

## Section A: Asia

### 1. Malaysia - Malaysia's Mangrove Ecosystem is at risk of collapse

The IUCN (International Union for Conservation of Nature) recently published the first-ever global assessment for mangrove ecosystems known as the Red List of Mangrove Ecosystems on May 22, 2024. The report showed that 50% of the mangrove ecosystems assessed are at risk of collapse (classed as either Vulnerable, Endangered, or Critically Endangered) including those in Malaysia (classed as Vulnerable (refer **Diagram 1**)).



Figure 1

Mangrove forest is one of the biomes found in Malaysia. **Diagram 2** indicates the distribution of mangrove forests in Malaysia. Basically, there are three different zones at mangrove swamp as shown in **Diagram 3**.

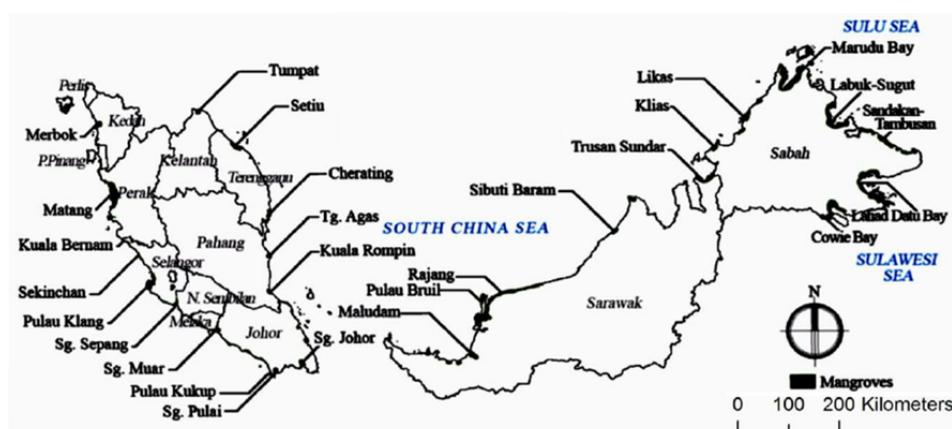
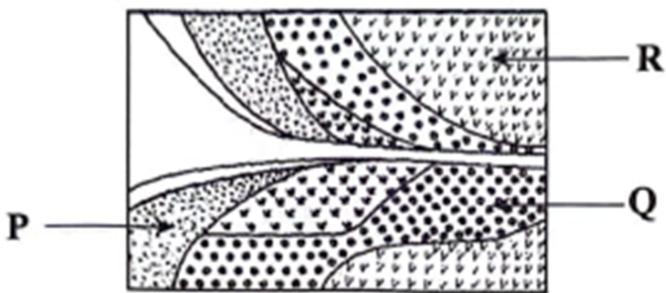


Figure 2



**Figure 3**

Which of the following match is correct between the zones and the mangrove species?

**4 marks**

	<b>P</b>	<b>Q</b>	<b>R</b>
A			
B			
C			
D			

## **2. China - Racing to 119!**

Element 119, also known as Ununennium (Uue) is a hypothetical element that has yet to be synthesised. An attempt to synthesise it was made by Heavy Ion Research Facility in Lanzhou this year, but it has been unsuccessful, and it has become less convincing for it to be made at this point. Regardless, chemists are still pursuing relentlessly to uncover the mystery behind Ununennium.

- (a) State the number of the group in the periodic table that Ununennium is classified into.

**1 mark**

- (b) The Lanzhou facility used Am-243 and Cr-54 to synthesise Ununennium this year.

**State** the nuclear reaction, given that the only product is Ununennium. **State** the atomic number **and** mass number of each element clearly.

**1 mark**

- (c) As of now, the most stable form of Ununennium ever synthesised is Uue-294, which has a half-life of 485 microsecond! **State** the nuclear reaction of the radioactive decay of Uue-294 to Pb-206, given that only alpha decay and beta minus decay occur.

**2 marks**

- (d) As a young science student, you may be inclined to think that the ionisation energy of an atom decreases when going down the group, but that is not always the case. Notably, Francium, which is in the seventh period, has a larger ionisation energy than Caesium, which is in the sixth period.

This is due to the relativistic effect, which essentially states that the closer to the speed of light the velocity of an electron is, the larger its mass, the stronger its attraction to the nucleus. It was also hypothesised that Uue might be able to exhibit multiple oxidation states, namely +1, +3 and +5.

What is the ratio of chlorine molecule to Ununennium atom if they are reacted together and the ratio of Ununennium (I) chloride: Ununennium (III) chloride: Ununennium (V) chloride is 4 : 3 : 2? Express the stoichiometric coefficients in **whole number**.

**3 marks**

## **3. Malaysia - Ministry of Finance Malaysia announced targeted subsidies for diesel**

Recently, YB Senator Datuk Seri Amir Hamzah Azizan, Finance Minister II, has announced the implementation of targeted subsidies for diesel, which involve setting the diesel fuel price to align with market price. This entails setting retail price for diesel fuel at RM3.35 per litre effective on 10th June 2024.

Targeted subsidies are a hot topic in Malaysia right now, especially with the government planning to implement them for petrol and diesel due to unsustainable costs being incurred by blanket subsidies. Moreover, there is also a suggestion to expand targeted subsidies to the EV & RE industry to boost them further in their initial stages.

- (a) How does the introduction of a targeted subsidy for electric vehicles (EVs) affect the market equilibrium in the EV market? Assume the subsidy is given directly to consumers in the form of a rebate.

**3 marks**

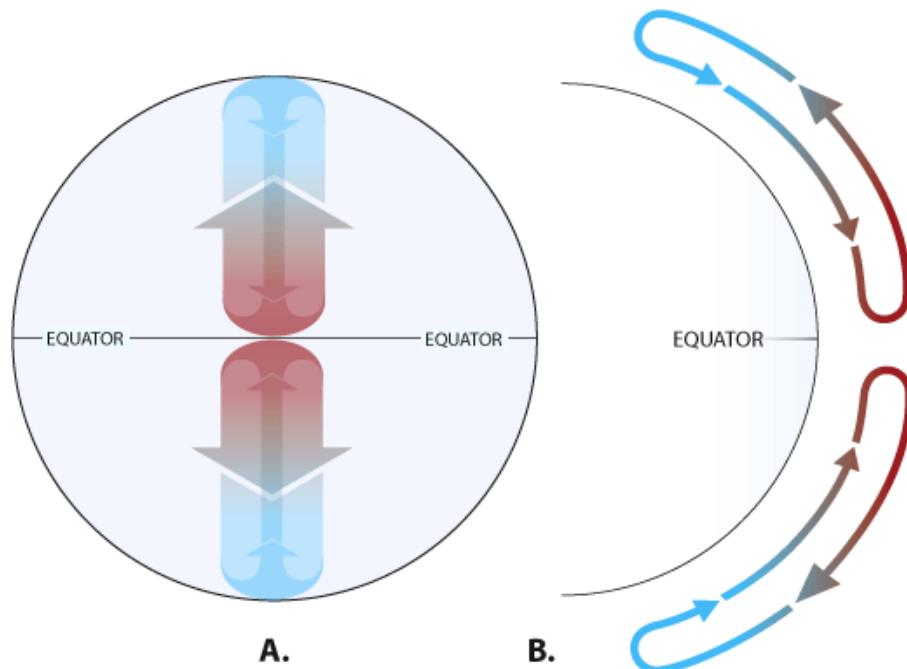
- (b) Consider a government that provides a targeted subsidy for renewable energy producers. Analyse the welfare effects of this subsidy on consumers, producers, and the overall economy. What are the potential deadweight losses or gains associated with this subsidy? 3 marks
- (c) Evaluate the fiscal implications of implementing a targeted subsidy for low-income families to purchase healthy food. What are the potential short-term and long-term fiscal impacts on the government's budget? 4 marks

#### 4. Philippines: The first tropical storm, Typhoon Ewiniar hit Philippines

Typhoon Ewiniar, known in the Philippines as Typhoon Aghon, was a fairly strong tropical cyclone that impacted parts of the Philippines, particularly Luzon, in May 2024. It resulted in 8 deaths and damage of more than 21 million PHP (RM1.7 million) to the agriculture sector in the Philippines.

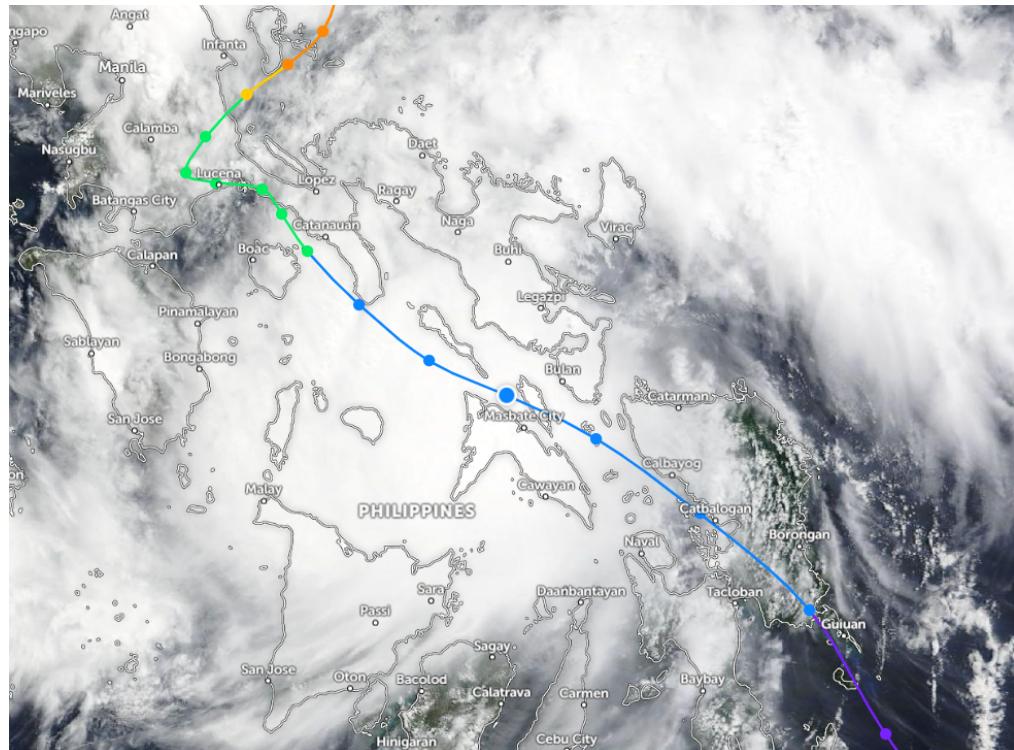
The Philippines is a country frequently affected by typhoons due to its geographical location in the Western area of the Pacific typhoon belt.

- (a) **Describe** the role of sea surface temperature (SST) in the formation of Typhoon Ewiniar. And **state** why are the SSTs in the western Pacific particularly conducive to typhoon development? 3 marks
- (b) The deflection of circulating air towards the right in the Northern Hemisphere and towards the left in the Southern Hemisphere is known as the Coriolis effect. Philippine's position in the tropical trade belt where the prevailing winds blow consistently from east to west results in low wind shear (change in wind speed). How did both the Coriolis effect and low wind shear conditions help form Typhoon Ewiniar? 4 marks



**Figure 4.** Coriolis effect.

- (c) **Evaluate** the potential impact of climate change on the frequency and intensity of typhoons in the Philippines. 3 marks
- (d) Which of the following are primary sources of energy that collectively drive the intensification of typhoons in the western Pacific, including those impacting the Philippines?  
**Select** two. 2 marks
- A. Solar radiation
  - B. Geothermal energy
  - C. Latent heat release from condensation
  - D. Oceanic Currents
- (e) The diagram below shows a satellite image of the path of Typhoon Ewiniar, starting from its formation. The orange section of the path depicts the typhoon fully formed. **Identify** the stages of the typhoon's formation path based on the colours of the path shown.
- (i) Purple:
  - (ii) Blue:
  - (iii) Green and yellow:



## 5. China - Advancement in Twin Prime Conjecture

Nearly a decade ago, in 2013, Chinese mathematician Yitang Zhang made a significant advancement in the twin prime conjecture. This conjecture states that there are infinitely many pairs of prime numbers that differ by exactly 2, such as (3, 5) and (11, 13). Zhang's breakthrough showed that there are infinitely many pairs of primes that differ by less than 70 million (later improved to less than or equal to 246). Although the nature of twin primes remains mysterious, we will explore a small part of this mystery. **Determine with proof** if there is a pair of twin primes whose sum is a power of 4. 5 marks

6. **Macao, China - ITTF World Cup Macao 2024: The competition that united globe's top table tennis talents**

From the 15th to the 21st of April, the International Table Tennis Federation (ITTF) hosted the 2024 Singles' World Cup in Macao, China after a hiatus of three years since 2021.

- (a) Spins on balls can result in a curved trajectory, usually attributed to the presence of the *Magnus force*. Referring to **Figure 5**, consider a ball with *side-spin* (i.e. it is spinning clockwise or counterclockwise when viewed from the top). As a physicist in the audience, you wish to provide a simple analysis of the Magnus effect. Using your knowledge of *Bernoulli's principle*, estimate the dependence of the Magnus force  $F_M$  on the velocity  $v$ , angular velocity  $\omega$ , radius  $r$  of the ball, and the density of air  $\rho$ . Assume there is no wind in the stadium. **State** your answer in the form

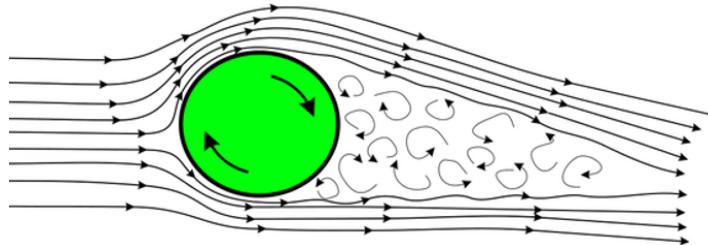
$$F_M \sim \rho^a v^b \omega^c r^d$$

where  $a, b, c, d$  are integers, together with the direction of the force.

**3 marks**

**Hint:**

At some point in your argument, you need to show that a quantity can be neglected. To do so, you may use the fact that the typical velocity of balls during a rally is  $10 \text{ m s}^{-1}$  and the angular velocity is  $\omega = 1000 \text{ rpm}$ . The radius of the ball is  $r = 20 \text{ mm}$ .



**Figure 5.** Top view of a ball with *side-spin* (taken from Wikipedia).

- (b) One of the most important techniques for players with attack-oriented styles is the *forehand loop*. For the laymen, it is akin to a 'smash' where the player's hand swings through a relatively large angle, hitting the ball during the process.



**Figure 6.** Chinese player Ma Long (in blue) executing a forehand loop during the ITTF World Cup Macao 2024 Men's Finals (source: *ITTF*)

If the swing is fast enough, it can generate substantial pressure at the player's fingertips, resulting in a tingling sensation. Your task is to estimate this additional blood pressure; you may assume that the player's arm remains straight and can be modelled as a hollow cylinder of length  $L = 70\text{ cm}$  filled with blood. The angle  $\theta(t)$  in degrees the arm makes with its initial position can be modelled as

$$\theta(t) = 7200 \left( \frac{t^2 T}{2} - \frac{t^3}{3} \right), \quad 0 \leq t \leq T,$$

where  $T = 0.5\text{ s}$  is the duration of a swing. Take the density of blood to be  $\rho = 1000\text{ kg m}^{-3}$ . Neglect gravity. 3 marks

## 7. Bhutan - Liberal PDP won parliamentary elections in Bhutan

Earlier this year, Bhutan, a country nestled between India and China which pioneered the usage of Gross National Happiness (GNH) in gauging its economic growth, held a general election. Results of the election revealed that People's Democratic Party (PDP) successfully secured 30 out of 47 parliamentary seats. Thanks to the party's victory, Tshering Tobgay becomes the prime minister of Bhutan for the second time.

Dzongkha is the national language of Bhutan. It belongs to the Sino-Tibetan language family and is spoken by approximately 640 000 people.

Here are some equalities written in the Dzongkha language:

1.	$gu \times cu-ci = khe zi da cy-gu$
2.	$khe ci: da zi + khe ko-da sum = khe sum da cy-gu$
3.	$(ci: + ge:)^2 = khe zi da ci:$
4.	$khe ko-da 'ni - ce-ŋa = khe ci:$
5.	$cu-ɖu \times 'ŋa = khe zi$
6.	$khe 'ni da zi + khe ci: da ɖhu: = khe pʃe-da zi$
7.	$cop-ge + cy-zi = khe ci: da cu-ni$
8.	$khe pʃe-da 'ni: + dyn = khe ci: da cup-dʒ$
9.	$khe zi da cu-ɖu - khe 'ni da cu-sum = khe 'ni da sum$

**Note (Please read very carefully):**

- 1) “ ‘ ” indicates stress
- 2) “ : ” indicates that the vowel is long
- 3) “ ~ ” indicates that the vowel is nasalised
- 4) “ ʈ ”, “ ɖ ”, “ ɳ ”, “ ɻ ”, “ ɲ ” are consonants

(a) Write the equalities (1–9) in digits, given that all words have a numerical value of less than 100. 18 marks

(b) Write the following numbers in the Dzongkha language. 6 marks

(i) 10

(ii) 34

(iii) 75

(iv) 90

## Section B: Americas

### 1. USA, Mexico, Canada - Rare solar eclipse swept across North America

The month of April saw the arrival of a phenomenal astronomical event in North America - the Solar Eclipse of April 8, 2024. In the northwestern United States, the Pomo, an indigenous group of people who live there, often tell a story of a bear who started a fight with the Sun and took a bite out of it which resulted in the solar eclipse. In fact, the Pomo name for a solar eclipse is “Sun got bit by a bear”.



Diagram 1. Various myths about solar eclipse.

It attracted large crowds of astronomy enthusiasts to witness this event. Kin Him, one of the astronomy enthusiasts, decided to observe the eclipse and travelled to Rochester, United States of America (latitude:  $+43^\circ$ , longitude:  $-77^\circ$ ) for this. Kin Him photographed the eclipse by using a camera (matrix size =  $22.3 \times 14.9$  mm, number of pixels of matrix =  $6000 \times 4000$ ) equipped with an objective lens (diameter  $D = 45$  mm, focal length  $f = 250$  mm).

- (a) **Calculate** all the parameters (dimensions, angles) necessary for subquestion (b). Assume geocentric angular diameters of the Sun and the Moon during eclipse hours are  $30.92'$  and  $30.49'$  respectively. 3 marks

**Note:** ' denotes arcminute, e.g.  $30.92' = 30.92$  arcminutes.

- (b) **Illustrate** how the image will look like when it is printed with a resolution of 300 pixels per inch by Kin Him. In the image, include important details, points and lines (for example, diameter of the Sun and Moon, the width of the “ring” formed by the Moon blocking the Sun, ratio of actual image to your sketch if you are drawing it bigger than it should). The “top” direction in your drawing should coincide with the “top” direction in the sky. 2 marks

**Hint:** 1 inch = 25.4 mm

- (c) **Determine** whether the eclipse visible in the previous paragraph is total or annular. Answer only in English “Total” or “Annular”. 1 mark
- (d) The next annular solar eclipse will take place during October 2024, covering parts of South America, Antarctica and the Pacific Ocean. **Estimate** the date of the next eclipse. 2 marks

## 2. North, Central and South America - Number of dengue cases in the Americas broke previous records

According to the Pan American Health Organization (PAHO), dengue cases are surging in the Americas, with cases reported topping 5.2 million as of April, surpassing a yearly record set in 2023. Due to climate change, dengue fever, once endemic to the tropics, now threatens the U.S. as the habitat of the mosquitoes that carry the disease is expanding, allowing them to spread further north.

Just like Malaysia, *Aedes aegypti* is the vector that spread dengue fever in the Americas, and the application of insecticides to water bodies is occasionally conducted to control mosquito populations. In a mosquito population, there are two alleles of a locus that affect susceptibility to pesticides, (s): susceptible, and (r): resistant. The resistance is completely recessive. The table below shows the change in the number of individuals with different genotypes before (Pre-1990), during (1990 – 2000; shown by an arrow), and after (2005 – 2015) pesticide application.



	s/s	s/r	r/r
Pre-1990	222	3	0
1990	31	12	4
1995	26	35	41
2000	2	12	126
2005	74	64	44
2010	165	45	20
2015	210	12	1

**Indicate** which of the following statements is **TRUE** or **FALSE**?

[6 marks]

- (a) No resistance allele was present before insecticide application.
- (b) During pesticide application, natural selection favoured the resistance allele.
- (c) Resistant individuals (r/r) are likely to have lower fitness than others (s/r, s/s) in the absence of pesticide application.
- (d) From 1990 to 1995, the frequency of the resistant allele increased more than 10 times.

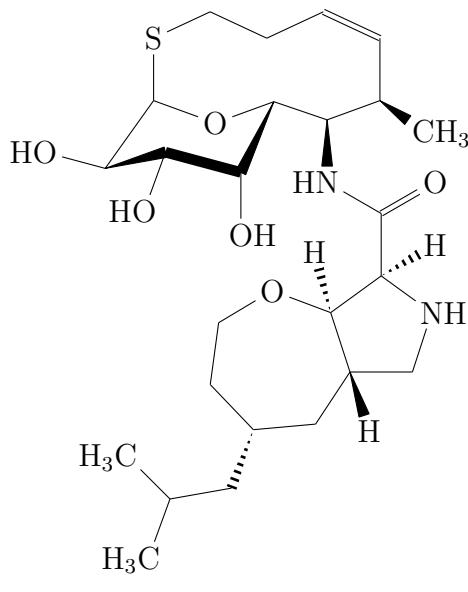
3. **USA - Harvard scientists have created a new antibiotic - a potential weapon against superbugs**

Dr Andrew Myers and his research team at Harvard University have created a fully synthetic antibiotic called cresomycin. This antibiotic was developed based on the chemical structures of lincosamides, a class of antibiotics that includes the commonly prescribed clindamycin.

Their findings, reported in the journal *Science* on 15 February 2024, revealed that cresomycin was able to kill both Gram-positive and Gram-negative bacteria, including those with multidrug-resistant ability such as *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli*. This was achieved by its strong binding to the ribosome, which inhibited protein production, ultimately hindering the proliferation and growth of bacteria.

A Boston University-based global nonprofit partnership, CARB-X has rewarded Dr Myer's team \$1.2 million to advance this potentially-life-saving antibiotic through preclinical studies with the hope to prevent millions of lives from succumbing to superbugs.

The structure of cresomycin is illustrated below:



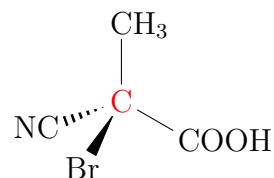
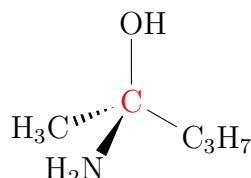
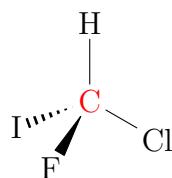
Cresomycin

On the structure of cresomycin in the **answer booklet**, **circle** all the chiral carbon centres.

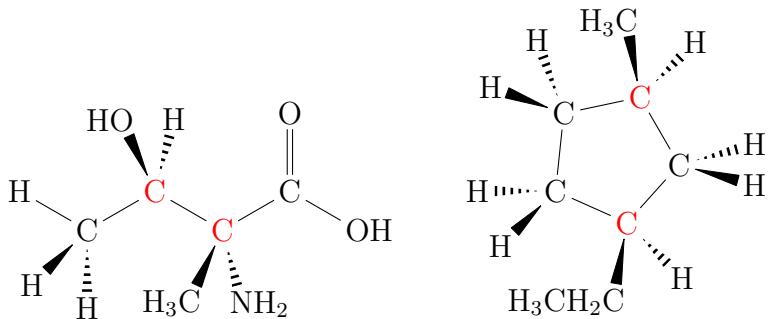
**5.5 marks**

**Hints:**

**Chiral carbon centres** are carbon atoms that are bonded to 4 different substituents. For instance, each molecule shown below has a chiral carbon centre (coloured in red) that is bonded to 4 different substituents:



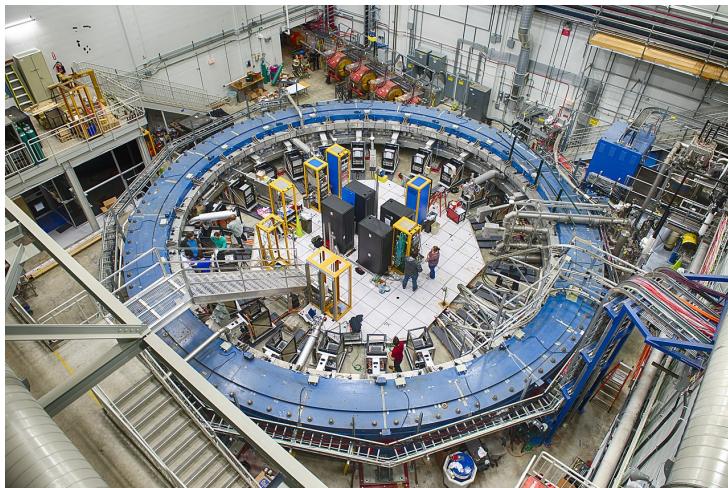
There can also be multiple chiral carbon centres in an organic compound. For instance, each organic compound shown below has chiral carbon centres (coloured in red as well) that are bonded to 4 different substituents:



#### 4. USA - Fermilab's Muon g – 2 experiment unveiled new insights into particle physics

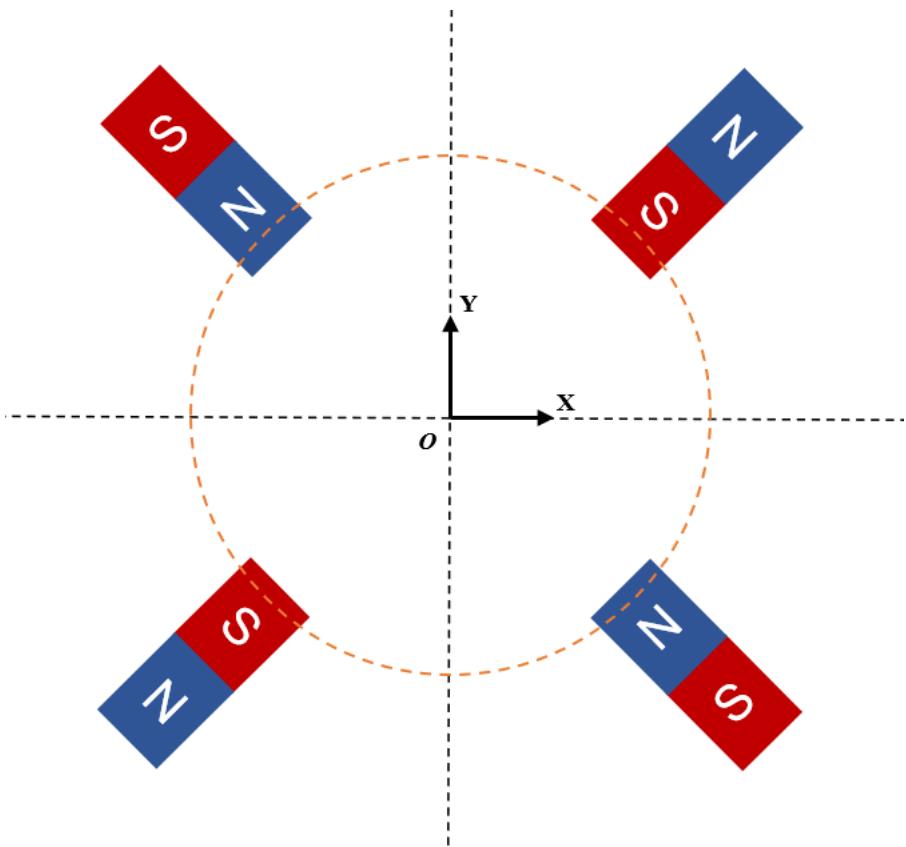
The Muon  $g - 2$  experiment is a highly sensitive experiment done over the course of 6 years (data collection ended in 2023) to measure the anomalous magnetic dipole moment of a muon. As published recently, the results are highly suggestive of new physics beyond the Standard Model.

- (a) To better analyse the behaviour of muons, it is desirable to ‘confine’ them by means of a storage ring.



**Figure 1.** The  $g - 2$  storage-ring magnet.

In some designs, this is achieved by using a quadrupole-magnet configuration. A simplified diagram is shown in **Figure 2** (next page).



**Figure 2.** A cross-section of a storage ring comprising a simplified quadrupole magnet schematic (drawn to scale).  $O$  is the center of the cross-section.

- (i) On **Figure 2** in the **answer sheet**, draw 4 magnetic field lines within the dotted circle. Each line should be symmetric across the four quadrants. Remember to indicate the direction of the field lines for which you will primarily be graded.

**1.5 marks**

- (ii) A centered beam of *negative muons* (which have a charge equal to an electron's) is shot into the storage ring perpendicularly into the page. Along which direction(s) ( $x$  or  $y$ ) will the beam be *focused* (i.e. the particles in the beam tend to converge together along that direction)?

**1.5 marks**

- (b) A positron (the antiparticle of the electron) and an electron are detected in the storage ring. Initially, the positron was stationary, and the electron, far away from the positron, had a velocity of  $\mathbf{v}_0$ . If we extend the line parallel to  $\mathbf{v}_0$  from the electron's initial position, its shortest (perpendicular) distance from the positron's initial position is  $d$  (this is also known as the *impact parameter*). Classically, what should be the distance of closest approach between the two particles? Express your answer in terms of the given variables and any physical constants.

**4 marks**

**Here is some useful information:**

- A positron has the same mass but opposite charge as an electron.
- Assume there is no loss due to radiation, and neglect the gravitational potential energy.

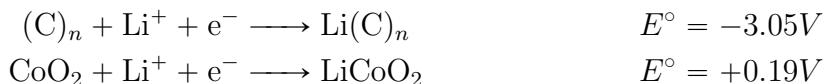
## Section C: Europe

### 1. Sweden - Nobel Prize in Chemistry 2019 was awarded to the inventors of Lithium-ion batteries

In 2019, the Nobel Prize in Chemistry was awarded to John B. Goodenough, M. Stanley Whittingham and Akira Yoshino for their contributions to the development of the lithium-ion battery (LIB). Thanks to this invention, we are able to use our wireless electronics and even electric vehicles without changing the batteries too often.

LIB are well-known for their high charge density, which makes them one of the most ubiquitous batteries nowadays. However, LIBs are notorious for being flammable due to their highly reactive nature. Elon Musk from Tesla decided to hire you so that you can research more about batteries together with him!

In lithium-ion batteries, graphite is typically used for one of the electrodes, where lithium ions intercalate between the graphite layers. The other electrode is composed of lithium cobalt oxide, which can reversibly absorb lithium ions as they move between the electrodes during the charging and discharging cycles. Answer the calculation questions below with **three significant figures**.



- (a) List  $(\text{C})_n$  and  $\text{LiCoO}_2$  as either the cathode or anode during the charging cycle.

**1 mark**

- (b) Write the chemical equation of the **charging cycle** and calculate the minimum voltage needed to recharge the battery.

**1 mark**

- (c) To better understand the efficiency of a battery, one could calculate the Faradaic efficiency. This quantity can be derived from the ratio of the charge used for producing a specific electrolysis product ( $Q_{\text{product}}$ ) to the total charge ( $Q_{\text{total}}$ ) transferred at the electrode surface during the electrolysis reaction. The sum of Faradaic efficiencies of all formed products adds to 100%.

$$\text{Faradaic Efficiency equation: } \text{FE}_{\text{product}} = \frac{Q_{\text{product}}}{Q_{\text{tot}}} \times 100\%$$

To celebrate you as their new employee, Elon awarded you with a Tesla Model X. It has a daily electricity consumption of 12kWh as you only use it for an average of 4 hours a day. Given that the Faradaic Efficiency of  $\text{LiCoO}_2$  is 90% in a Lithium-ion battery, calculate the number of moles of  $\text{LiCoO}_2$  formed per day, assuming that the emf of the battery is minimal and stays constant throughout the day. Take note that the battery is always in **standard condition**.

**3 marks**

- (d) In reality, however, the electromotive force (emf) of the battery decreases as more and more products are being formed. One can picture this scenario by using Le Chatelier's

Principle, which states that a system always tries to counteract the change imposed upon itself. In other words, as there are more and more LiCoO<sub>2</sub> being produced, the reaction becomes less and less favourable as the chemical system wants to counteract the change such that the amount of LiCoO<sub>2</sub> produced will be lesser, causing the cell potential to decrease.

Assuming that both the cathode and anode have the same volume, one could use the Nernst's Equation to calculate the new emf, which is stated below, where  $n$  is number of moles of electrons transferred and  $T$  is temperature:

$$E = E^\circ - \frac{1.984 \times 10^{-4}T}{n} \log \left( \frac{\text{no.mol Li}^+ \text{ in cathode}}{\text{no.mol Li}^+ \text{ in anode}} \right)$$

What is the new emf if the total number of moles of LiCoO<sub>2</sub> is 10 times of Li(C)<sub>n</sub> at 313 K? 2 marks

- (e) Elon wants you to calculate how much a Tesla Model 3 sample battery weighs. The lead engineer left you with a note that the battery has an average current of 3.0 A that can typically last for 5 hours, and 1 mol of graphite can hold a maximum of 0.4 mol of Li<sup>+</sup>. Assuming that initially lithium is only present in the anode and after 5 hours lithium is only present in the cathode, and the mass of the other battery components is 200 g, what is the minimum mass of the battery required? Provide your answer in **three significant figures**. 4 marks
- (f) Now that you have calculated the mass of the battery, Elon thinks that you are a capable employee! He asks you to investigate the standard cell potential if sodium ion was used instead of lithium-ion. Before he left, he reminded you that the intercalation of ions within graphite releases energy during the charging cycle. The bigger the ion is, the smaller the energy released. **State** whether the standard cell potential of sodium ion battery will be larger/smaller than lithium ion battery. 2 marks

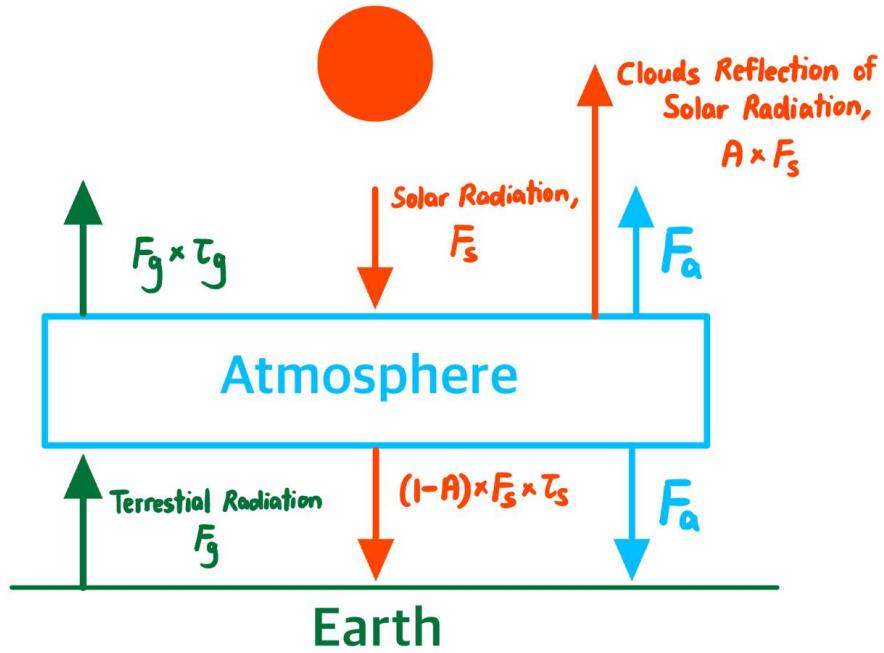
**Hint:**

You should consider both ionisation energy (i.e. the energy required for one mole of atoms to lose one mole of electrons to form one mole of +1 ions (in the case of Li<sup>+</sup> and Na<sup>+</sup> ions)) and energy released during intercalation.

## 2. Sweden - Nobel Prize in Physics 2021 awarded for understanding Earth's climate and how humanity influences it.

The Nobel Prize in Physics 2021 was awarded to Syukuro Manabe and Klaus Hasselmann for laying the foundation of our knowledge of the Earth's climate and how humanity influences it. The Earth's climate is one of many examples of complex systems. Manabe and Hasselmann are awarded the Nobel Prize for their pioneering work on developing climate models.

Inspired by this news, Hua Zhi, a student of environmental sciences, is exploring the impacts of Earth's atmosphere on global warming using a simplified single-layer model. This model helps to understand how Earth retains warmth thanks to its atmospheric blanket.



The single-layer model provides a basic way to illustrate how some of the sun's radiation is trapped by the atmosphere, warming the planet. Unlike more complex models, it assumes a straightforward radiation balance.

Help Hua Zhi calculate with steps the terrestrial radiation flux,  $F_g$ , in  $\text{W/m}^2$ , rounded to the nearest integer, reaching Earth's surface under equilibrium conditions using the single-layer model with these parameters:

- Solar irradiance at the top of the atmosphere ( $F_s$ ) = 340  $\text{W/m}^2$
- Earth's Albedo ( $A$ ) = 30%
- Atmospheric transmissivity for solar radiation ( $\tau_s$ ) = 77%
- Atmospheric transmissivity for terrestrial radiation ( $\tau_g$ ) = 10%

Assume all the Earth's heat comes from solar radiation ( $F_g = (1 - A) \times F_s \times \tau_s + F_a$ ) and that the atmosphere itself absorbs 0 net radiation. This calculation will help understand the basic dynamics of Earth's energy balance and can be a stepping stone to more detailed climatic models.

3 marks

## Section D: Oceania

### 1. Vanuatu - Nine small island states including Vanuatu secured historic climate win at international ocean court

On 21st May 2024, nine small island states won a historic climate change case at the International Tribunal for the Law of the Sea (ITLOS). The win had successfully redefined marine pollution by which it includes greenhouse gas emissions absorbed by the ocean. This urged countries to enhance their protection of marine environments beyond the obligations set by the Paris climate agreement.

Vanuatu was one of the nine island states that secured the historic win. Vanuatu has three official languages with Bislama being one of them. It is spoken by approximately 200 000 people.

- (a) **Match** the words in Bislama (1-13) to their English Translations (A-M). Write down the answers only, for example **1. A.**

6.5 marks

Words in Bislama		English Translations	
1.	mitufala	A.	Yawn
2.	olgeta	B.	We two (Exclusive)
3.	yumi	C.	They three
4.	smolpima	D.	Dugong
5.	mifala	E.	We (Exclusive)
6.	kaofis	F.	You (Plural)
7.	ol nani	G.	Chickens
8.	luksave	H.	They (Plural)
9.	yufala	I.	We (Inclusive)
10.	wantem silip	J.	Goats
11.	ol faol	K.	Bird's eye chilli
12.	trifala	L.	We two (Inclusive)
13.	yumitu	M.	Recognise

(Note: Inclusive / Exclusive **means** Including / Excluding addressee)

- (b) **Translate** the following words in English to Bislama.

4 marks

- (i) Goat
- (ii) You three
- (iii) Chilli
- (iv) Fish

## 2. New Zealand: New Zealand's new government plans to scrap tobacco endgame policy to fund tax cuts

Last December, New Zealand's new government announced their plan to reverse their ambitious tobacco endgame policy to fund tax cuts - a move which will potentially affect the Māori communities the most.

Generational endgame for smoking is a policy piloted by New Zealand to prevent younger generations from smoking to create a smoking-free society in the future. However, there are major implications to this, not least the lobbying from the tobacco industry. As of now, only 3 countries have started work on the proposal: New Zealand, Malaysia and the UK.

- (a) How will New Zealand's generational endgame smoking plan, which aims to prohibit the sale of tobacco to individuals born after 2008, impact the country's tobacco industry in terms of employment, production, and sales? 3 marks
- (b) Analyse the potential long-term healthcare cost savings for New Zealand's public health system resulting from the generational endgame smoking plan. Consider the impact on the prevalence of smoking-related diseases and the associated treatment costs. 3 marks
- (c) Evaluate the effects of New Zealand's generational endgame smoking plan on government tax revenue from tobacco sales. What alternative fiscal strategies could the government implement to compensate for the expected decrease in tobacco tax revenue? 4 marks

## 3. Australia - Terence Tao is the first UCLA math professor to win Fields Medal

In 2006, Terence Tao won a Fields Medal, considered the Nobel Prize for Mathematics, for his contributions to partial differential equations, combinatorics, harmonic analysis and additive number theory. He is also the first UCLA math professor to win such prestigious award. Among his major contributions to Mathematics is his progress on the  $3n + 1$  conjecture, a simple-looking problem that turns out to be notoriously difficult and left unsolved to this day.

Let's consider a similar-looking but much simpler version. We start with a single positive integer  $N$ , and in each step, we will replace our integer. The rule of replacement is that if our current number is  $X$ , then the next number will be

$$\begin{cases} \frac{X}{2} & \text{if } X \text{ is even.} \\ X + 1 & \text{otherwise.} \end{cases}$$

It's known that no matter which number we start with, we will eventually end up with the number 1. For example,  $54 \rightarrow 27 \rightarrow 28 \rightarrow 14 \rightarrow 7 \rightarrow 8 \rightarrow 4 \rightarrow 2 \rightarrow 1$ . Given that  $N$  has at most three digits and it takes  $k$  steps to reach the number 1 for the first time, determine with proof the maximum possible value of  $k$ . 6 marks

## Section E: Antarctica

### 1. Antarctica - World Penguin Day: A day to honour Adélie Penguins

World Penguin Day is observed yearly on April 25. This day was established at McMurdo Station, an American research facility located on Ross Island. World Penguin Day honours the Adélie Penguin (**Diagram 4**), a species of penguin that begins its annual migration northward toward Antarctica on April 25.

Let's understand Adélie Penguins. When both parents leave the nest to find food, three-weeks-old chicks' group together for protection. In this species, social defence behaviour can occur in unusual ways. When adult Adélie penguins reach the coast, they gather in groups before diving into the ocean, where usually their predator (leopard seal) could be lurking. The penguins have two choices, first to dive together, or wait until one of penguins' dives so they could make sure if there is a predator or not.



**Diagram 4**

**Indicate** which of the following statements is **TRUE** or **FALSE**?

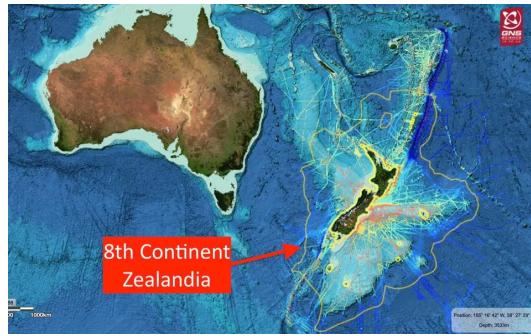
4 marks

- (a) This is an example of altruism behaviour as the penguin that jump first could be hunted by possible predators while transferring its genes by helping its relatives.
- (b) According to the above example we can say one individual has influence on what other penguins are doing.
- (c) If a new strategy arose which would make a penguin trip another one into the ocean without retaliation from others, everyone in the population would adopt this new strategy in the long run.
- (d) A mutation that results in postponing to jump as long as possible would eventually go to fixation.

## Section F: Zealandia

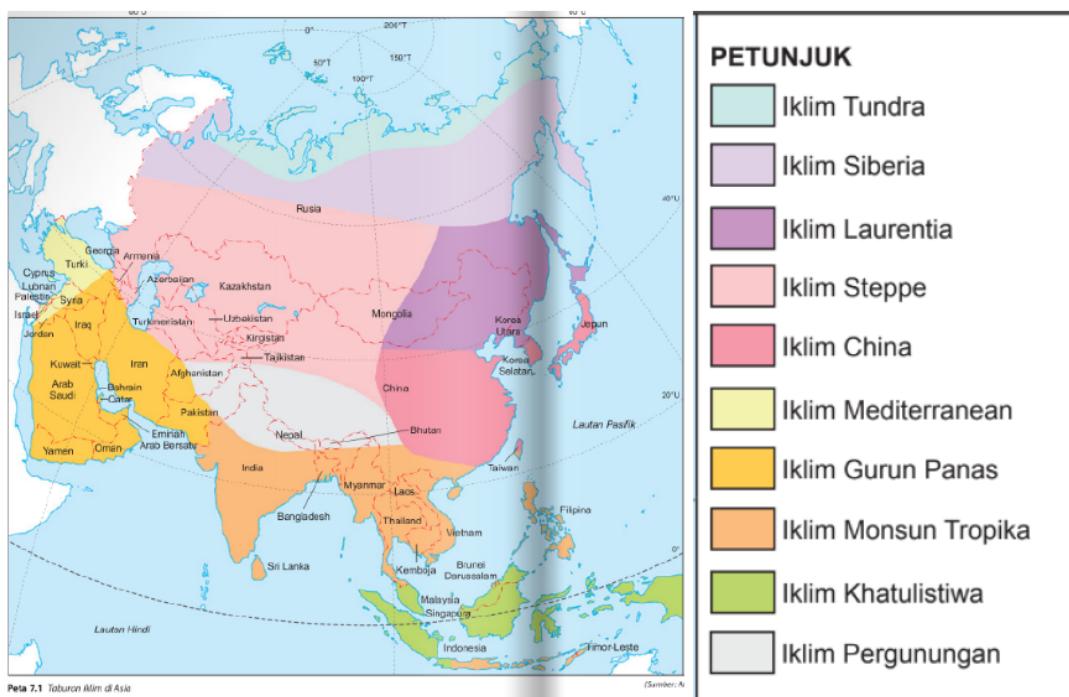
### 1. Zealandia - Scientists discovered the eighth continent!

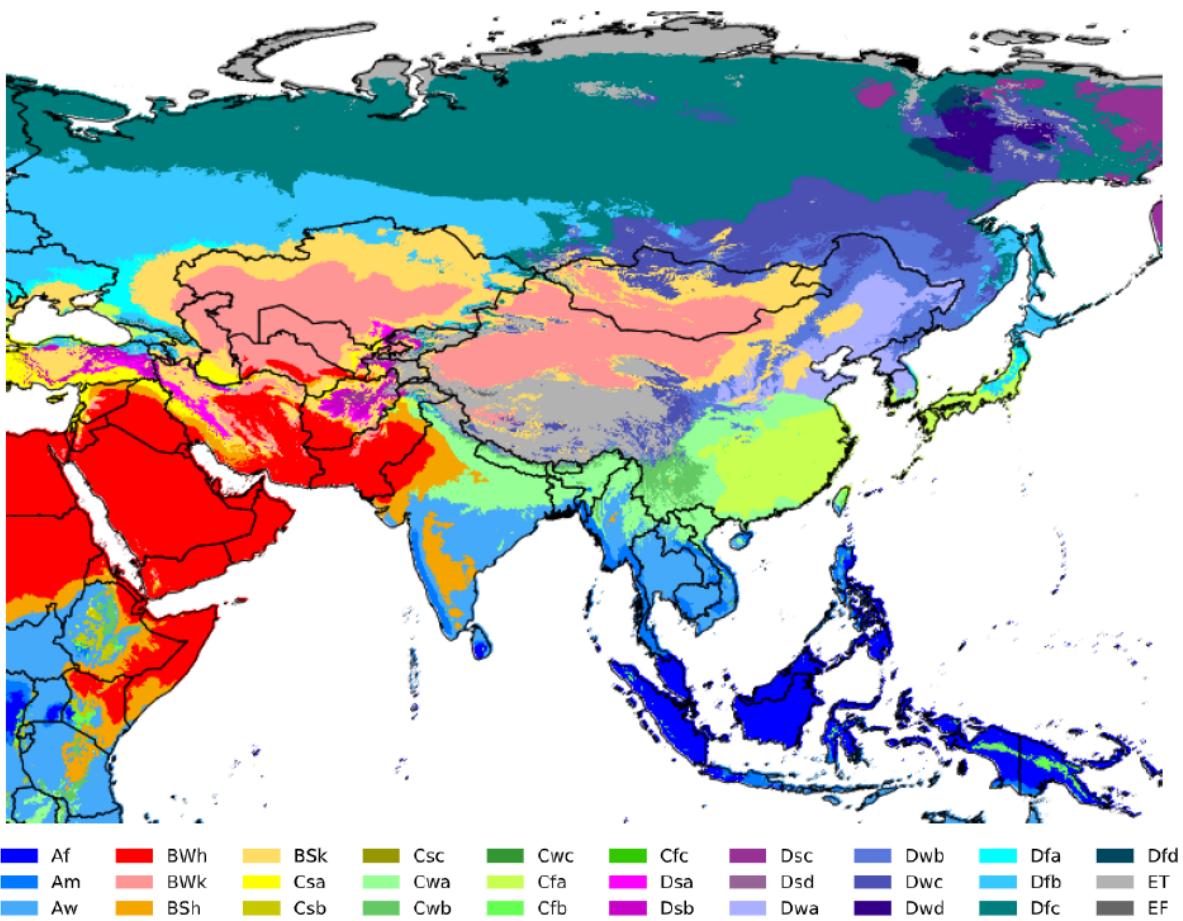
Last year, scientists have announced the discovery of the eighth continent known as Zealandia, a long-lost continent submerged beneath the ocean's surface for 375 years. About 94 percent of Zealandia is underwater with the only above water landmasses making up a few Pacific islands including New Zealand.



Although we now know that there are 8 known continents, most of the time, our planet doesn't always neatly fit into categories like continents. Nevertheless, there are other ways to categorise areas on Earth. For example, we can use the temperature and precipitation throughout the year to assign a climate to different areas.

The Köppen climate classification scheme (**Map 2**) divides climates into five main climate groups, indicated by the first letter of the climate type: **A**, **B**, **C**, **D**, and **E**. The second letter indicates the seasonal precipitation type, while the third letter indicates the level of heat.





**Map 2.** Köppen climate classification.

Based on **Map 1** and **Map 2** and your own knowledge:

- (a) What does climate group B represent? 2 mark
- A. Low temperature
  - B. Low precipitation
  - C. High temperature
  - D. High precipitation in summer months
- (b) Which climate group gets the most precipitation? 2 mark
- A. A
  - B. B
  - C. C
  - D. D
- (c) Which of the following is **TRUE**? 2 mark
- A. The lack of rain in arid (desert) climates prevent all forms of agricultural practices.
  - B. Only arid climates have low precipitation.
  - C. Places with climate group **D** are generally colder than places with climate group **C**.
  - D. Tropical monsoon climate gets more rainfall than tropical rainforest climate (iklim Khatulistiwa).

# Answers

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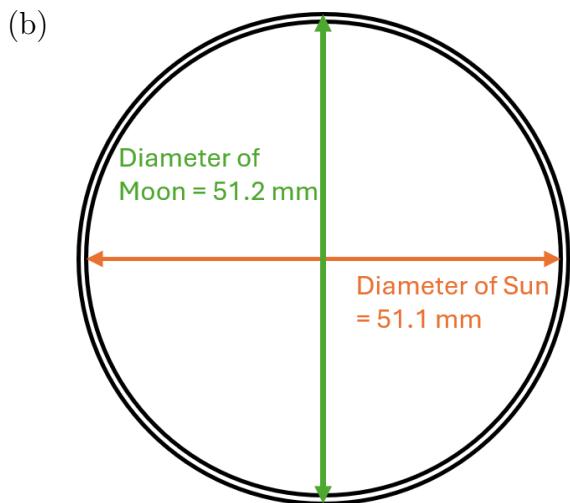
## Section A: Asia

1. B
2. (a) Group 1  
(b)  $^{243}_{95}\text{Am} + ^{54}_{24}\text{Cr} \longrightarrow ^{297}_{119}\text{Uue}$   
(c)  $^{294}_{119}\text{Uue} \longrightarrow ^{206}_{82}\text{Pb} + 22\ ^4_2\alpha + 7\ ^0_{-1}\beta$   
(d) 23:18 or 11.5:9
3. (a) Accept any points that show a subsidy lowers price and hence increases quantity demanded.  
Award marks for additional explanation e.g. equilibrium point.  
(b) Accept any points that relate to consumer and producer surplus correctly. Correct interpretation of deadweight loss. Award marks for additional explanation on welfare.  
(c) Accept any points that relate to the short-term and long-term impacts correctly.
4. (a) Accept any points that correctly describe how warmer SSTs provide the energy necessary for convection, evaporation processes into typhoon formation. Subsequently describe, in any capacity, why Western Pacific countries have warmer SSTs.  
(b) Accept any points that accurately link how rotation of air from Coriolis effect creates a turning motion, thus producing a typhoon. Subsequently link how low wind shear conditions facilitate the typhoon's formation and structure. Accurate technical terms used if any at all.
- (c) Accept any points that link higher global temperatures due to climate change to greater numbers of, longer-lasting, and more intense typhoons. Any valid description of impact on typhoons (e.g increased moisture content so more rainfall, increased wind speeds, etc) can be accepted.
- (d) A, C
- (e) Purple: Tropical disturbance  
Blue: Tropical Depression  
Green and Yellow: Tropical Storm (Severe)
5. No.  
Accept any plausible proofs or explanations that support the above statement.
6. (a)  $F_M \sim \rho v \omega r^3$   
(b) 15 kPa
7. (a) 1.  $9 \times 11 = 99$   
2.  $24 + 55 = 79$   
3.  $(1+8)^2 = 81$   
4.  $35 - 15 = 20$   
5.  $16 \times 5 = 80$   
6.  $44 + 26 = 70$   
7.  $18 + 14 = 32$   
8.  $30 + 7 = 37$   
9.  $96 - 53 = 43$
- (b) (i) cu  
(ii) khe ci: da cy-zí  
(iii) khe ko-da zi  
(iv) khe pye-da 'ña

## Section B: Americas

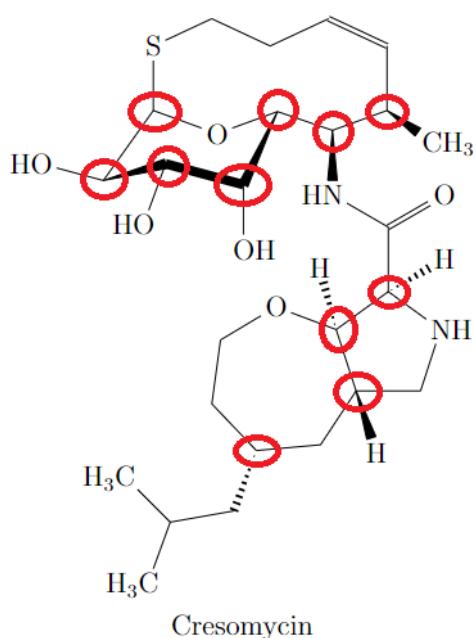
1. (a) Diameter of the Sun on the matrix: 2.2499 mm,  
Number of pixels (Sun): 604 px

Diameter of the Moon on the matrix: 2.2536 mm,  
Number of pixels (Moon):  
605 px

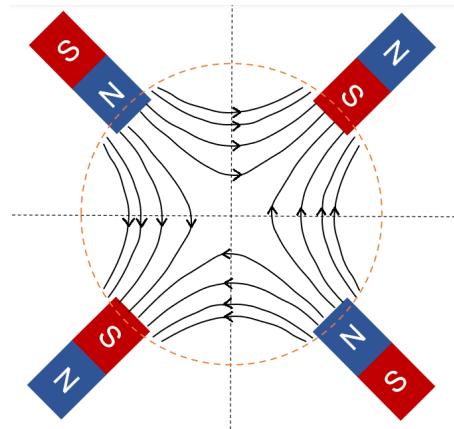


- (c) Total  
(d) 2/10/2024 or 2nd October 2024  
or October 2nd 2024

2. (a) False (c) True  
(b) True (d) False



4. (a) (i)



(ii) x-direction

$$(b) \quad r = -\frac{2ke^2}{mv_0^2} + \sqrt{\frac{4k^2e^4}{m^2v_0^4} + d^2}$$

or

$$r = -\frac{e^2}{2\pi\epsilon_0 m v_0^2} + \sqrt{\frac{e^4}{4\pi^2\epsilon_0^2 m^2 v_0^4} + d^2}$$

## Section C: Europe

1. (a) (C)<sub>n</sub>/Graphite: Cathode  
LiCoO<sub>2</sub>: Anode

(b) Chemical equation:  
$$(C)_n + LiCoO_2 \longrightarrow Li(C)_n + CoO_2$$
Minimum voltage required:  
+3.24 V

(c) 124 mol

(d) 3.18 V

(e) 271.62 g

(f) Smaller

2. 383 W/m<sup>2</sup>

## Section D: Oceania

- |        |      |       |       |
|--------|------|-------|-------|
| 1. (a) | 1. B | 6. D  | 11. G |
|        | 2. H | 7. J  | 12. C |
|        | 3. I | 8. M  | 13. L |
|        | 4. K | 9. F  |       |
|        | 5. E | 10. A |       |

2. (a) Accept any points that relate to the effect of the plan to the country's tobacco industry in terms of employment, production and sales correctly. Award marks for additional explanation if applicable.

(b) Accept points that relate to a reduction in smoking-related diseases, savings to healthcare costs and additional analysis that are correctly linked.

(c) Accept any points that relate to a decrease in tax revenue. Accept any alternative fiscal strategies mentioned that are realistic to implement. Award marks for additional analysis and explanation.

3. 19

## Section E: Antarctica



## Section F: Zealandia

1. (a) B (b) A (c) C

# References

---

## Section A: Asia

1. The images in **Q1** are sourced from:
  - International Union for Conservation of Nature and Natural Resources (IUCN). The first-ever global assessment for the IUCN Red List of Ecosystems reveals that more than half of the world's mangroves are at risk of collapse by 2050 [Image on the internet]. 2024 May 30 [cited 2024 June 1]. Available from: <https://www.iucn.org/story/202405/first-ever-global-assessment-iucn-red-list-ecosystems-reveals-more-half-worlds#:~:text=30%20May%2C%202024-,The%20first%20ever%20global%20assessment%20for%20the%20IUCN%20Red%20List,2024%20marks%20a%20significant%20milestone>.
  - Kanniah K, Sheikhi A, Cracknell A, Goh H, Tan K, Ho C, et al. Satellite images for monitoring mangrove cover changes in a fast growing economic region in southern Peninsular Malaysia. *Remote Sensing*. 2015 Oct 29;7(11):14360–85. Available from: <https://doi.org/10.3390/rs71114360>
2. **Q1** is adapted from:  
Kompilasi Kertas Percubaan MRSM SPM Biology (Cerdik)
3. The images in **Q4** are sourced from:
  - National Oceanic and Atmospheric Administration. The Coriolis Effect [Image on the internet]. 2013 [cited 2024 June 10]. Available from: [https://oceanservice.noaa.gov/education/tutorial\\_currents/04currents1.html](https://oceanservice.noaa.gov/education/tutorial_currents/04currents1.html)
  - <https://zoom.earth/storms/ewiniar-2024/#map=satellite-hd>

## Section B: Americas

1. The image in **Q1** is sourced from:  
Ellis E. Solar Eclipse 2017! [Image on the internet]. FCM; 2017 Aug 18 [cited 2024 June 12]. Available from: <https://fuelcellmaterials.com/solar-eclipse-2017/>
2. **Q2** is adapted from:  
International Biology Olympiad (IBO) 2020.
3. The image in **Q4** is sourced from:  
Hahn R. Muon g-2 Experiment [Image on the internet]. Washington DC: U.S. Department of Energy; 2017 Aug 28 [cited 2024 June 4]. Available from: <https://vms.fnal.gov/asset/detail?recid=1950114>

## Section E: Antarctica

1. The image in **Q1** is sourced from:  
Klappenbach L. Adelie Penguin Pictures [Image on the internet]. ThoughtCo; 2019 July 3

[cited 2024 April 3]. Available from: <https://www.thoughtco.com/adelie-penguin-pictures-4122626>

## Section F: Zealandia

1. The images in Q1 are sourced from:

- Nace T. Stunning New Maps Reveal What The Lost Continent Of Zealandia Looks Like [Image on the internet]. Forbes; 2020 June 29 [cited 2024 June 12]. Available from: <https://www.forbes.com/sites/trevornace/2020/06/29/stunning-new-maps-reveal-what-the-lost-continent-of-zealandia-looks-like/>
- Yoeng KC, Ismail ZB, Subramaniam R. Kepelbagaian iklim dan pengaruhnya terhadap kegiatan manusia di Asia. In: Suppiah P, Termizi NASB, editors. Geografi Tingkatan 2. Kementerian Pendidikan Malaysia; 2017. p. 108-109. Available from: <https://anyflip.com/yghbl/tmdw>
- Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific data. 2018 Oct 30;5:180214. Available from: <https://doi.org/10.1038/sdata.2018.214>