



Indian Institute of Science Education and Research, Tirupati
ABHIPRAJNA 2023 (Prelims)
THEME QUESTION PAPER

Date: September 17, 2023

Maximum points: 50

Instructions:

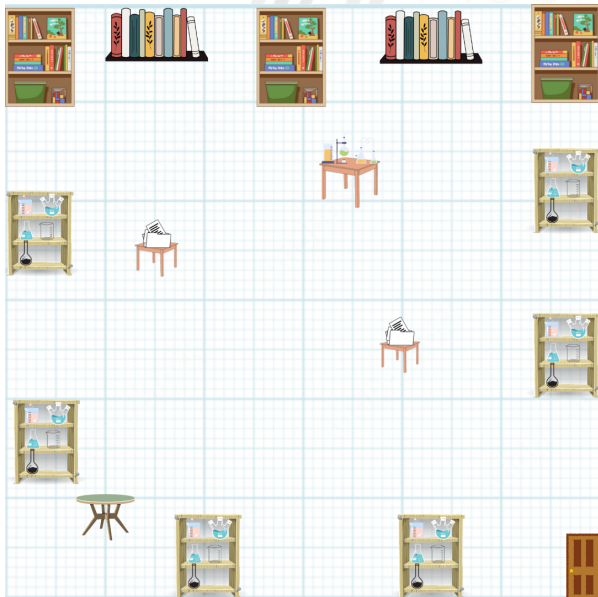
- All questions are mandatory
- The question paper consists of 8 questions plus a puzzle question at the end spread over 9 pages which total to 50 points (40 + 10)
- Answers must be written in legible and readable handwriting, failing which that question shall not be considered for evaluation.
- *Click this link for submitting your solution PDF:*
<https://forms.gle/kp7Cfc7Va3xT2oL37>

You and your team are a Covert Ops team of Good Guys, and you're tasked with finding the military secrets of the enemy so the war can be finished as soon as possible. In your last mission to Craevania, you were alerted to a sample of a Deadly Bioweapon, which was developed at a lab by an evil scientist in the city of Kovalengrad, who was possibly working on an antidote.

The Good Guys launch a ground-based attack and lay siege to the city, so your team finds a cover to enter the city.

You see an opening in the frontlines and you are able to enter the city safely. After navigating the empty city and escaping the occasional enemy soldiers and firing, you make your way to the local university in the city. The enemy scientists' boss has a lab that can be accessed only through his office at his university.

You enter the scientists' office and see a few very important-looking documents open on the table. As you decide to investigate the room, a trap is triggered.



1. (10 points)

Assume the door is at the coordinates (12,0). When you reach the first desk at coordinates (2,2), a trap is sprung, and a toxic gas enters the room. The gas is toxic upon exposure and is more dangerous in higher/increasing concentrations. You need to escape the room but don't forget there's potentially important information in the documents on the table. The following equation gives the concentration of the gas in the room.

$$S(x, y, t) = 3 - e^{-5t}(\sin(x) + \cos(y))$$

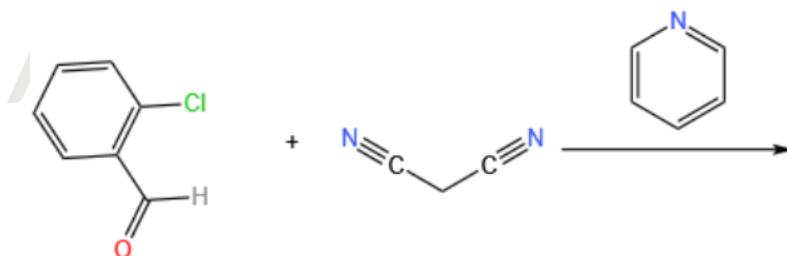
Use MS Paint or any other tool, and **Draw the fastest path in the room to exit while collecting the documents from all the desks and reducing the exposure to the toxic gas as much as possible. Explain why your path is the best route.**

Hint: The Diffusion of the gas follows the following equation: (D is a positive constant)

$$\frac{\partial S}{\partial t} = D \nabla^2 S$$

Assume the furniture does not get in the way of your movement, and you can walk through the furniture. Your path must only go through the points where the tables with documents are there.

Despite your best efforts, one of your comrades is finding themselves affected by the toxic gas. They suffer from extensive coughing, severe skin irritation, vomiting, prostration, and lacrimation. You find the source of the gas as a chemical container labeled X. A few grenades nearby indicate that this chemical X is deployed in the form of a grenade that consists of various toxic pyrotechnic mixtures to use in the form of aerosol as chemical X exists as solid in the room temperature with the below preparation technique used by the enemy troops.



2. (4 points)

Identify X with the help of the reaction above and justify your answer with the appropriate reaction mechanism.

You take your comrade to the first aid room nearby. As a measure of first aid, their contaminated uniform with armor was removed and was thoroughly washed with a non-irritable chemical. Few hours after cleansing with the chemical, their symptoms were resolved completely and they were fit enough to continue the mission.

3. (1 points)

Predict the possible fundamental chemical properties of the particular chemical that was potent enough to treat this irritant exposure.

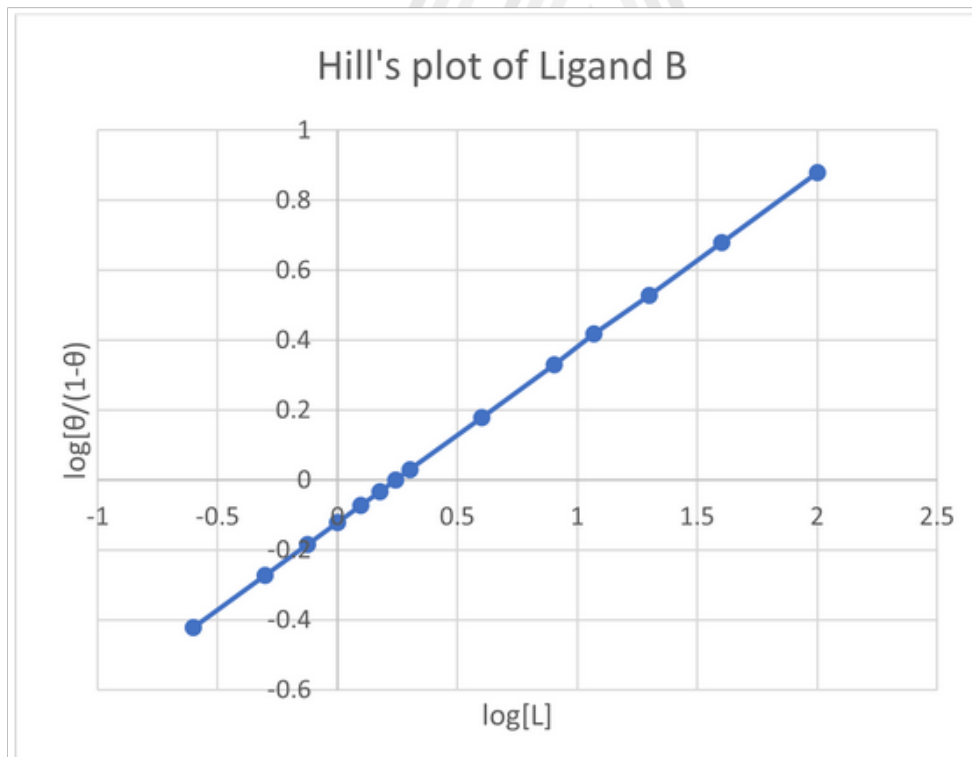
After returning to base camp, you find out a group of scientists were researching the site of action of this irritant in our body. They found out that a particular nociceptor named TRPA1 was responsible for the sensation of pain which is felt when the irritant binds to the receptor. The TRPA1 receptor has cysteine residues in the proteins' N-terminus and scientists believe it has some important structural and functional roles.

4. (1 points)

With this information, comment on how the irritant X would bind to this receptor with respect to their chemical structures and their nature of reactivity.

The scientists also discovered a particular compound B to be one of the ligands of the receptor TRPA1. Ligand binding studies were done by adding the ligand to the receptor in vitro. The results are shown in the form of a table and with a hill's plot. Here, $[L]$ is the concentration of the ligand and θ shows the fraction of TRPA1 receptors bound by the ligand.

S. No	[L] (mM)	θ	S. no	[L] (mM)	θ
1	0.25	0.274	9	4	0.602
2	0.5	0.348	10	8	0.681
3	0.75	0.395	11	12	0.724
4	1.00	0.431	12	20	0.771
5	1.25	0.458	13	40	0.827
6	1.5	0.481	14	80	0.871
7	1.75	0.500	15	100	0.883
8	2.00	0.516			



5. (4 points)

With the help of the data, calculate the hill's coefficient and the equilibrium dissociation constant. Also, draw a schematic ligand binding curve in coordinates θ versus $[L]$. How do you think the presence of ligand B affects the binding of the irritant of X to the receptor? Justify your answer.

Now that your comrade is recovered, you now focus on the documents you took from the lab, it appear to be experiments regarding the manufacture of a bioweapon and figuring out an antidote for the same. The enemy scientists had already run some experiments and collected data but did not get a chance to analyze them before he had to flee. It appears his specific brand of bioweapon was a form of viral bioweapon. Today, ongoing research and surveillance aim to detect and prevent the development of viral bioweapons, focusing on public health readiness and international cooperation. Persistent viral infections could cause neurologic or psychiatric diseases through selective effects on brain levels of neurotransmitter mRNAs.

You see one of the files includes data on kinetics experiments on some recent experiments involving kinetics on various samples. With your limited knowledge of the local language, you can understand one of the samples corresponds to the Bioweapon, however you cannot figure out which of the three it is.

Shown below is the data you have gathered. Note: $[S]$ is given in mM; other values represent observed V_o values given in units of mol product formed per minute.

$[S]$ (mM)	V_o (Sample 1)	V_o (Sample 2)	V_o (Sample 3)
20	0.05	0.05	0.05
80	0.03	0.20	0.15
160	0.46	0.35	0.24
300	0.5	0.50	0.30

6. (4 points)

Because you do not know with certainty the amounts of each inhibitor in the solution (for example, the amount of the Bioweapon you are adding to the assay). you cannot directly compare the magnitude of inhibition shown by the Bioweapon and by the gathered samples. How, then, can these samples be distinguished and compared using enzyme kinetics?

Reading another document taken from the lab, you realize it is from a lab in Kashoesau, who was working on making a drug to test it's effectiveness against the virus. It appears they wanted to have an antidote ready, in case the bioweapon affected their own people.

The document describes an experiment where a group of 170 victims have been recruited. Antiviral treatment was administered to the test group along with a

placebo for the control group and the newly synthesized drug to another test group for 18 months. Note that the patients have been equally assigned to the three groups. You are asked to measure the effectiveness of the newly synthesized drug and the anti-viral treatment against the control group by regressing the binary variables *Vir* and *Neuro* on their effectiveness in delaying the replication of the virus at the end of 18 months. $Vir = 1$ if the newly synthesized drug is administered and $Vir = 0$ otherwise. *Neuro* is a binary variable (1 if the treatment is effective in delaying virus replication, 0 otherwise). The cells affected are inversely related to the rate of replication of the virus in the patient's body. Assume that only one type of treatment is administered to a particular group throughout the experiment. A post-it note in the report has a scribbled equation which appears to be a regression equation.

$$\text{Effectiveness in delaying virus replication} = 250 + 71 \cdot \text{Vir} + 76 \cdot \text{Neuro}$$

7. (6 points)

- (i) **Estimate the average treatment effect (ATE) of the drug. Also, state the test statistic associated with the test the company wants to conduct.**
- (ii) **Find out the difference in the average treatment effect (ATE) of the anti-viral treatment and the newly synthesized drug.**

Having analyzed the data, and a new target for your next mission, Kashoessau, you are ready to come out of the city. You reach a pre-decided-upon extraction point - the clock tower of the university. You climb the tower for your pickup, and you notice the battlefield outside the city. Being able to see the battlefield from a bird's eye view, you are in an excellent position to formulate a strategy and advise the general who's overseeing the siege and is responsible for picking your team up.

The only easy entry to the city is through a narrow twisting valley going north to south, with mountains on the east and the west sides. This had made things easy to sneak your team into the city, however, it presented a challenge for your General coordinating the attack.

8. (10 points)

Both the armies of the Good Guys and the Kovalengrad Defences are stationed at equal distances from the ends of the valley. Both armies consist of troops and tankers, with the Kovalengrad Defences having **30%** of tankers, and the Good Guys having **40%** of tankers. The troops from both armies are at the front, facing each other. When the battle commences, the troops initiate combat in a manner where,

at any given moment, an equal number of frontline soldiers from both armies are actively engaged in firing, while the others remain stationary and advance as the soldier in front of them succumbs. Meanwhile, the tankers from both armies form the rearguard and simultaneously fire their weaponry while remaining stationary.

(The probability that the tankers from the Kovalengrad Defences army malfunctions is denoted as "p," and the probability that the tankers from the Good Guys army malfunctions is denoted as "q.")

Take $p = 0.6$ and $q = 0.3$

Given the following information:

- Denote initial number of soldiers in Kovalengrad Defences as R_0 and Good Guys as B_0 . Given $\frac{R_0}{B_0} = 1.3$
- The troop effectiveness of the Kovalengrad Defences = $\alpha = 0.35$ ($0 \leq \alpha \leq 1$)
- The troop effectiveness of the Good Guys = $\beta = 0.2$ ($0 \leq \beta \leq 1$)
- The tanker effectiveness of both armies = 2.5

(Here effectiveness is defined as no. of opponent soldiers killed per unit time by the troops or tankers)

- (i) **In the north of the valley, you see a symmetric battle scenario (i.e., both sides employ the same tactics and attacking techniques). Determine the rate at which the Good Guys and Kovalengrad Defences soldiers' numbers are diminishing through the use of differential equations. Additionally, if possible, predict which side will emerge victorious after a certain extended period of time.**

Now in the South of the valley, you see a somewhat asymmetrical scenario where both the factions do not have tanker support. In this case, the defending Kovalengrad Defence force strategically positions itself at an advantageous point, gaining control over the entrance to the passage. This strategic placement allows them to concentrate their firepower on the approaching Good Guys attacking force. Due to the constraints imposed by the terrain, the Good Guys force moves in a linear formation and employs the firing tactics mentioned earlier. As a result, the Kovalengrad force can engage in direct fire from all its units and tankers, taking advantage of their elevated and superior position, while the Good Guys force can only use its forward-facing weaponry while on the move.

- (ii) **Given this situation, determine, using differential equations, the rate at which the number of Kovalengrad troops and Good Guys troops decrease over time. Additionally, predict by what factor 'gamma' the Good Guys need to increase their initial troop strength to achieve parity with the Red force.**

Having understood the battlefield dynamics, you devise a exit strategy and send out a message to Base Camp for pickup.

The Puzzle Round: (10 point)

You summarize your Mission Report and Recommended Battle Plan using a highly sophisticated encryption algorithm, which your comrades can decode only using a key. however, as the key was not pre-determined, you send the key using an older, WWII-era cipher, which you know can be cracked by your comrades. The Very famous - - - - - M3 Cipher. (What's - - - - -?)

The message - "ufkdg airax lxjvn ttctx npzdw"

The message successfully reaches your comrades, and they try to crack it. Here's how they do it:

Look at all the answers to the hint questions.

1. The Physics hint - Solve the hint Q for total d.o.f with $d = 1$. Note the number.
2. The Chemistry hint - The answer has two words. Note the first letter of both words.
3. The Biology hint - The answer is one word. Note the first and the last letter of the word.
4. The Mathematics hint - Consider the second part of the starred Q. The answer is a number. Write it in words, note the first and the last letters of the word.

Clue - Look up a cipher decoder for this cipher. Enter the following parameters.

Guessing the cipher should be fairly simple :)

Rotor	Position	Ring
Rotor - 1 Answer to Physics hint Q, with $d = 1$.	First letter of first word of Chemistry hint Q.	First letter of second word of Chemistry hint Q.
Rotor - 2 Answer to Physics hint Q, with $d = 1$.	First letter of Biology hint Q.	Last letter Biology hint Q.
Rotor - 3 Answer to Physics hint Q, with $d = 1$.	First letter of Mathematics hint Q.	Last letter of Mathematics hint Q.

Plugboard - none ; Reflector - UKWB

What is the message your team sent over using this cipher?

Having decoded the cipher, they get access and read your mission report, and send a team to pick you up. Another Successful Mission, to bring the war one step closer to completion. Salud.

Click this link for submitting your solution PDF:

<https://forms.gle/kp7Cfc7Va3xT2oL37>

