SigmaCamp Qualification Quiz 2024

This Qualification Quiz is only one part of your application to SigmaCamp. For full instructions, please check https://sigmacamp.org/2024/apply.

The Qualification Quiz contains two problems from each of the six main disciplines at Sigma – math, physics, chemistry, biology, computer science, and linguistics & applied sciences. The second problem in each category was designed to be more challenging than the first problem. **You are not expected to solve all the problems.** We will evaluate your quiz submission based on your approach to the problems and the quality of reasoning.

You can use the Internet, books and even help from someone (who is not another applicant), but **state precisely what sources you have used to solve each problem**. Note that you cannot post the problems to the Internet or other public forums and solicit help that way.

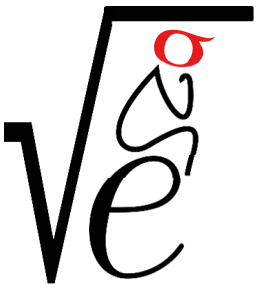
You cannot collaborate with other applicants.

1. Your solutions should be submitted either as `.pdf` or plain text (`.txt`) files, with the exception of Computer Science, where it should be `.java` or `.py` files (see Computer Science section below for more details).
2. Your solutions can be handwritten or typed. Handwritten solutions must be scanned as `.pdf` (not as `.jpg` or `.png`) files.
3. Files containing solutions should be named as follows: `Subject.ProblemNumber.Yourname.extension`, where Subject is Math, Physics, Biology, Chemistry, CS or Linguistics. `ProblemNumber` can be `1` or `2`, corresponding to the problem number in the corresponding subject. For example, here are valid file names: `Chemistry.1.John Smith.pdf`, `Biology.2.Jane.Miller.txt`, `CS.1.SamJohnson.java`.
4. Each solution should be submitted in a separate file. Please don't combine the solutions for problems 1 and 2 of the same subject into one file, and also don't combine the solutions across subjects.
5. If you were accepted to Sigma through the Problem of the Month contest (POM), you do not need to submit the QQ. **If you participated in POM, but were not admitted among the top scorers, your effort will not be forgotten: 30% of your cumulative POM score will be added to your QQ score.**

The application deadline is April 15, 2024 – all your materials (Qualification Quiz, essay, letters of recommendation) must be submitted by that date. We will notify all applicants no later than May 5, 2024.

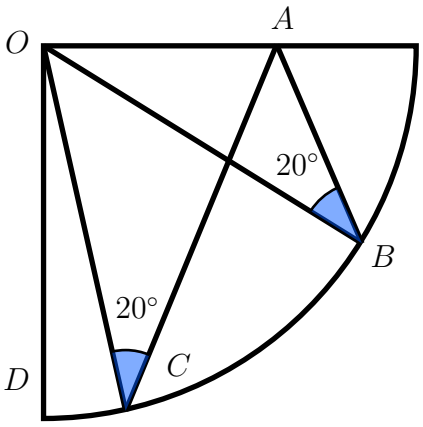
Good luck with your application!

Mathematics



Problem 1 (5 points):

Given that $\angle DOC = 15°$ and O is the center of the quarter circle shown below, find $\angle BOA$.



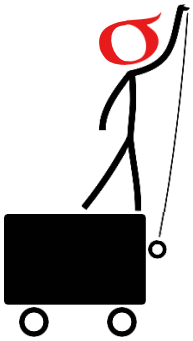
Note that a numerical answer alone will receive no credit. To receive credit, you have to provide a proof of your answer.

Problem 2 (10 points):

There are 1000 statues lined up in a row, all initially facing forward. For every number n from 1 to 1000 inclusive, you rotate each nth statue 72° counterclockwise (so first if $n = 2$, you rotate the 2nd, 4th, 6th, 8th, etc.). Which statues are facing forward at the end?

Physics

Problem 1 (5 points):



Consider a box filled with an ideal gas at temperature T. One of the walls of the box is a movable piston (depicted in Figure 1). Imagine the size of the box is doubled by moving the piston. In both instances, the gas expands *adiabatically* (the only transfer of energy between the gas and the oustide world is the work done on the piston by the gas.)

(a) If the piston moves much *slower* than the typical molecular velocity, what is the final temperature of the box?

(b) If the piston moves much *faster* than the typical molecular velocity, what is the final temperature of the box?

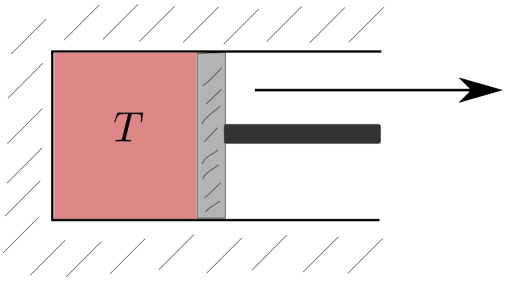
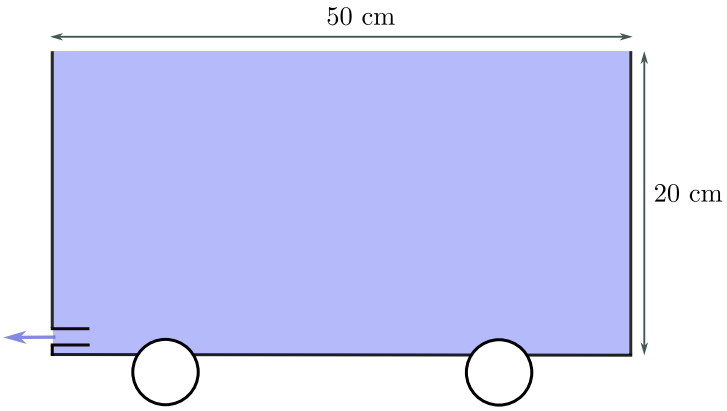


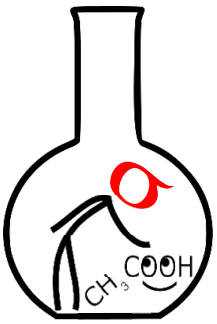
Figure 1: A container of ideal gas at temperature T. One of the walls of the container is a movable piston.

Problem 2 (10 points):

A cart full of water stays still on a horizontal surface. The dimensions of this cart are 50 × 20 × 20 cm (length × height × width). The cart starts moving when the circular hole with a radius of 2 mm is poked at the bottom of the square side of the cart, and a hollow tube is inserted in this hole, as seen in the picture. Assuming the water loss is negligible and the cart's mass without water is zero, estimate how far the cart will travel in 10 seconds. How much water will the cart lose at the same time (in weight or the percentages of the total weight)?



Chemistry



Problem 1 (5 points):

You found four bottles in your garage, which could be some old stuff from your kitchen or laundry room. The bottles are old, and the labels are unreadable. You vaguely remember that these bottles may contain baking soda, table salt, citric acid, starch, baking powder, and borax. Before discarding the bottles, you decided, out of curiosity, to determine which compound is in which bottle. Of course, the first step could be to taste these powders, however, since one bottle could potentially be borax, you decided not to taste those powders, assuming that each of them may be potentially toxic.

You labelled the bottles as "A", "B", "C", and "D", and you made the following experiments.

First, you took a teaspoon of each powder and added it to separate glasses full of water. The powder A, and D completely dissolved. The powders from the bottles B formed a white suspension, whereas C formed a thick semitransparent suspension.

When you mixed the solutions A and D, bubbles of some gas formed.

You put all four powders into a tea spoon (one spoon for each powder), placed them on a tray and put them into a hot oven at 230°C, you observed melting of the powder D, whereas A and B remained solids, although their appearance slightly changed. The powder C remained solid, but its color gradually changed to brown.

When you put the powder C into an open fire, it rapidly decomposed into a dark brown substance with an unpleasant odour.

Determine which substances are in the bottles A - D and explain your answer. Which substances from the above list are NOT present in the bottles A - D? You can do that either by reading literature or by reproducing the above described experiments at home.

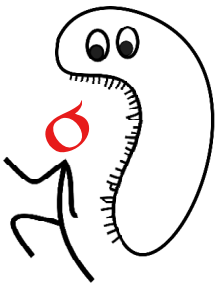
Problem 2 (10 points):

You have the following items:

- A roll of copper wire;
- A tungsten rod;
- A piece of bismuth;
- Two siding nails (aluminium);
- A zinc-coated nail;
- A piece of magnesium;
- A silver spoon;
- Various stuff that you may usually find in your kitchen.

What is the highest possible DC voltage that is possible to obtain using the above listed items? Describe your setup and explain your answer. The power source you build is expected to produce a stable DC for at least one minute, and you are not allowed to break or cut any items except the copper wire.

Biology



Problem 1 (5 points):

A ship with animals on board crashed into the sea. Only a couple of pandas, a couple of pumas, a couple of capybaras, a couple of iguanas, a couple of gopher tortoises and a couple of pigeons made it to the island. The island is covered with wet grass. The coast is rocky and is home to colonies of seagulls, the only large animals on the island. The climate is mild.

What animals could have been discovered on the island by an expedition that visited it 60 years after the shipwreck? For each species, draw a diagram showing population size (number of animals) over time and a couple of sentences explaining your answer.

Problem 2 (10 points):

ChatGPT 4.0 was asked a following question:

"There is a specific condition called "Compound X deficiency" in humans. People suffering from this condition were treated at one of the hospitals. The first cohort of patients with this deficiency was given Compound X-rich food. Some of the patients got better, but the conditions of others did not change. Doctors decided to give them Compound X as intravenous injections. This resulted again in the full recovery of some patients, but not all of them.

Could you suggest as many reasons as you can to explain this?"

ChatGPT's answer is shown below. It contains 13 possible explanations. Some of them are quite reasonable and correct, but some are meaningless, vague or have no scientific value.

ChatGPT's answer:

Certainly, there could be several reasons why some patients with Compound X deficiency responded positively to Compound X-rich food while others did not, and why some responded to intravenous injections while others did not. Here are some possible explanations:

1. **Absorption and Bioavailability:** The ability of the body to absorb and utilize Compound X can vary between individuals. Oral intake of Compound X-rich food might not be as effective for some due to gastrointestinal issues that hinder absorption. Similarly, even with intravenous injections, individual differences in metabolism can influence the effectiveness of the treatment.
2. **Genetic Variability:** There may be genetic differences among the patients that influence how they respond to Compound X. Some patients may have genetic variations that affect their ability to metabolize or utilize Compound X effectively.
3. **Severity of Deficiency:** The severity of Compound X deficiency could vary among patients. Those with milder deficiencies may respond well to Compound X-rich food alone, while those with more severe deficiencies may require intravenous injections to reach therapeutic levels.
4. **Underlying Health Conditions:** Patients may have underlying health conditions or complications that affect their response to treatment. These conditions could impact the absorption, distribution, metabolism, or excretion of Compound X.
5. **Duration of Deficiency:** The duration of Compound X deficiency prior to treatment may influence response. Patients who have been deficient for longer periods may have experienced more extensive damage or complications, making it harder to reverse their symptoms.

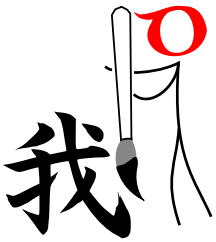
6. **Immunogenic Response:** Some patients may have developed an immune response to Compound X, leading to variability in effectiveness between individuals. This immune response could affect the efficacy of both oral and intravenous administration.
7. **Differences in Metabolism:** Variability in metabolic rates among patients could impact the efficiency of Compound X utilization. Patients with faster metabolisms may require higher doses or more frequent administration to achieve therapeutic levels.
8. **Adherence to Treatment:** Variations in patients' adherence to treatment regimens could contribute to differences in response. Patients who consistently adhere to dietary or injection protocols may experience better outcomes compared to those who do not.
9. **Drug Interactions:** Patients may be taking other medications that interact with Compound X, affecting its efficacy or metabolism. These interactions could differ between individuals and influence treatment outcomes.
10. **Patient Age:** Age-related factors such as developmental stage or age-related changes in metabolism could influence response to treatment. Pediatric or geriatric patients may respond differently to Compound X compared to adults.
11. **Individual Sensitivities or Allergies:** Some patients may have sensitivities or allergies to Compound X or its components, leading to variable responses to treatment.
12. **Dosage Variability:** Variations in the dosage or concentration of Compound X administered could lead to differences in response among patients. Individualized dosing based on factors such as weight, age, and severity of deficiency may be necessary for optimal outcomes.
13. **Patient's Overall Health Status:** Factors such as overall health, nutritional status, and immune function can influence response to treatment. Patients with compromised immune systems or poor nutritional status may have a diminished response to Compound X therapy.

    Considering these factors, it's important for healthcare providers to carefully assess each patient's individual characteristics and tailor treatment plans accordingly to optimize outcomes for those with Compound X deficiency.

Question:

Please identify the answers that seem the most relevant and correct, explain what answers are only marginally relevant, and, if you see any errors in the ChatGPT's answer, point them out. Explain your decision.

Linguistics & Applied Sciences

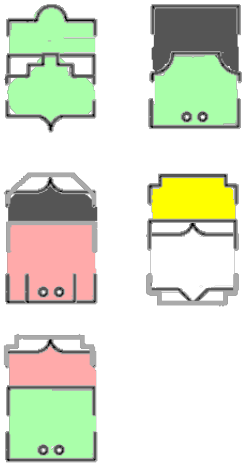


Problem 1 (5 points):

There exists an alternative script for English where the consonants are shaped brackets that can be combined with each other, and the vowel sounds are colors between them. For the purposes of this problem, we will refer to this alternate writing system for English as ColorBracket.

1. Match the following English words to their ColorBracket transliterations below.

A) whether
B) gradient
C) toughen
D) portable
E) brighten



2. Write the word "**snowing**" using ColorBracket. Please be as clear as possible with drawing your answer, and label any colors used for most accurate grading.

Problem 2 (10 points):

1. Match the following sentences in an unknown language to their English translations.

A) I am sleeping in the temple	i) tan-ten wenel yetel quna
B) I love the little island	ii) t-etš wenel yetel tsaqan
C) The little fox walked in the valley	iii) t-ten kimsah-ah sinaan
D) She loved you long ago	iv) tan-ten yakunah pe-peten
E) She will kill the lizard	v) t-ot-otš šimbal yetel tsaqan
F) You slept in the valley	vi) he-sinaan kimsah-e ot-otš
G) I killed the scorpion long ago	vii) t-u yakunah-ah-etš
H) The scorpion will kill the little fox	viii) he-u kimsah-e tolok

2. Translate the following sentence into the unknown language:

You killed the little fox long ago

Computer Science

- Your program should be written in Java or Python-3.
- No GUI should be used in your program (e.g. `easygui` in Python).
- All the input and output should be done through files named as specified in the problem statement.
- Java programs should be submitted in a file with extension `.java`; Python-3 programs should be submitted in a file with extension `.py`. **No `.txt`, `.dat`, `.pdf`, `.doc`, `.docx`, etc. Programs submitted in the incorrect format will not receive any points!**

Problem 1 (5 points):

You are modelling the properties and dynamics of steam. For one of your experiments, you create a complex network of pipes for steam to travel through. The pipes all go up along a wall, but split and rejoin many times. After you set a boiling pot of water below the setup, steam starts travelling through the pipe network. You want to determine how the steam flow evolves along this network, and measure the steam flow coming out of each pipe at the top.

At any height, there are n pipes, labelled from 1 to n from left to right. A pipe may fork and split into two pipes, increasing the total number of pipes by 1, or two pipes may rejoin, decreasing the total number of pipes by 1. After such a rejoining or split occurs, the pipes are consecutively renumbered from left to right.

You can assume that:

- There will always be at least one pipe.
- No steam is lost through condensation – all steam that enters the pipe network at the bottom will leave through the top.

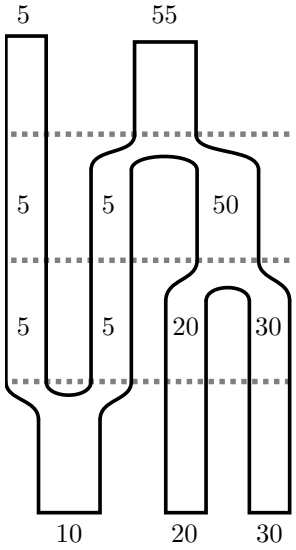


Figure 2: Steam enters the pipes with flows 10, 20 and 30, and exits with flows 5 and 55. Dashed lines indicate pipe splits/joins.

Input and output specifications:

Your program should read the input file `input.txt`, with the following specifications:

- The first line of `input.txt` will contain two space-separated integers n and m, where n represents the initial number of pipes, and m represents the number of splits/joins in the pipes. You can assume that $n \geq 1$ and $m \geq 0$.
- The second line contains a space-separated list of non-negative integers give the initial amount of steam in L/m (liters per minute) in each of the pipes from left to right.
- The next m lines will each be one of the two following formats:
  - "`SPLIT N P`", where `N` denotes the number of the pipe that is split, and the non-negative integer `P` denotes the percentage of steam that flows into the left pipe (the rest will flow into the right pipe). You can assume that $0 \leq \texttt{P} \leq 100$.
  - "`JOIN N`", where `N` denotes the number of the pipe that joins with the pipe immediately to the right of it.

You must determine the steam flow going through pipes $1, \ldots, \ell$, where ℓ is the number of pipes at the top of the pipe network. Your program should produce the file `output.txt` containing a space-separated list of integers corresponding to the steam flow going through each pipe *rounded to the nearest integer*.

Sample Input 1:

```
3 3
10 20 30
SPLIT 1 50
JOIN 3
JOIN 2
```

Sample Output 1:

```
5 55
```

Sample Explanation 1:

This is the example in Figure 2. There are initially three pipes with 10, 20, and 30 L/m of steam flow respectively. The first pipe splits into two pipes with 50% of the steam going into both branches, giving us four pipes with the following flows:

```
5 5 20 30
```

The third pipe then joins with the fourth, giving us:

```
5 5 50
```

Lastly, the second pipe joins with the third, giving us:

```
5 55
```

Sample Input 2:

```
2 4
5 20
SPLIT 2 68
SPLIT 1 50
SPLIT 1 50
SPLIT 4 10
```

Sample Output 2:

```
1 1 3 1 12 6
```

Sample Explanation 2:

There are initially two pipes with 5 and 20 L/m of steam flow respectively. The second pipe splits into two pipes with 68% of the steam going into the left pipe (and 32% in the right), giving us:

```
5 13.6 6.4
```

The first pipe then equally splits, giving:

```
2.5 2.5 13.6 6.4
```

The first pipe splits equally once more, giving:

```
1.25 1.25 2.5 13.6 6.4
```

The fourth pipe now splits with 10% of the steam going into the left pipe (and 90% into the right), giving:

```
1.25 1.25 2.5 1.36 12.24 6.4
```

Rounding these flows to the nearest integer gives us the desired output. Note that the sum of the flows in the output does not match the sum of the initial flows – this is not a mistake, but rather a consequence of the rounding.

Problem 2 (10 points):

It's semilab time! In a strange twist of events, SigmaCamp 2024 is one-dimensional, so all campers are traveling in on a straight line to get to their semilabs.Each camper i starts at location x_i, and their semilab is at location y_i, where x_i and y_i are integers satisfying $x_i < y_i$. All campers simultaneously start moving from their initial positions to the right at the same speed until they get to their semilab at location y_i. Each time a camper meets another camper at the same point, they will high-five each other once, even if one of the campers has already reached their destination. You are tasked with determining the total amount of high-fives that will occur as campers travel to their semilabs.

Input and output specifications:

Your program should read the input file `input.txt`, with the following specifications:

- The first line of `input.txt` will a single positive integer n, representing the number of campers.
- The next n lines will contain two space-separated integers x_i and y_i, representing the initial and final positions of each camper. It is guaranteed that $-10^9 \leq x_i < y_i \leq 10^9$.

Your program should produce the file `output.txt` containing a single integer denoting the total number of high-fives that will take place.

Sample Input 1:

```
2
3 4
1 5
```

Sample Output 1:

```
1
```

Sample Explanation 1:

The two campers will high-five each other at location 4.

Sample Input 2:

```
6
2 6
3 9
4 5
1 8
7 10
-2 100
```

Sample Output 2:

```
9
```

Sample Input 3:

```
5
-4 9
-2 5
3 4
6 7
8 10
```

Sample Output 3:

```
4
```