PROBLEMS SET

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Tbilisi – Georgia

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Problem 1
Chemical Traffic Lights

There is a power shortage at the busiest junction in your city, causing a massive traffic jam. As a chemist, you decided to save your city and design a chemical oscillator system that changes colour between green, yellow and red. However, to avoid accidents, it would be practical if the lights on roads crossing each other did not show yellow at the same time. Therefore, preferably, the chemical oscillation should change colour from green to yellow to red, and then to green (without a yellow phase between the red and green), starting the cycle again.

What would your reaction look like, how much time would the switch take, how many rotations would it last, and how much time would each side have to cross the road?

Problem 2
Ancient Water Treatment

Water has always been one of the most basic and valuable resources. For millennia, most major settlements have been established where water is easily accessible. However, various sources often contaminate it, including sediment, pathogens, and human activities. Therefore, treatment and decontamination have also been essential.

Devise a procedure for treating polluted water, using only materials and methods which would have been technologically feasible 2000 years ago in the Roman Empire. You can use any currently known information to design the procedure, but you must demonstrate that you can produce used materials and equipment. The treatment procedure should be capable of chemically disinfecting the water and eliminating typical pollutants of that period, such as common metallic contaminants, nitrogenous waste and phosphates, all on a scale appropriate to ancient cities.

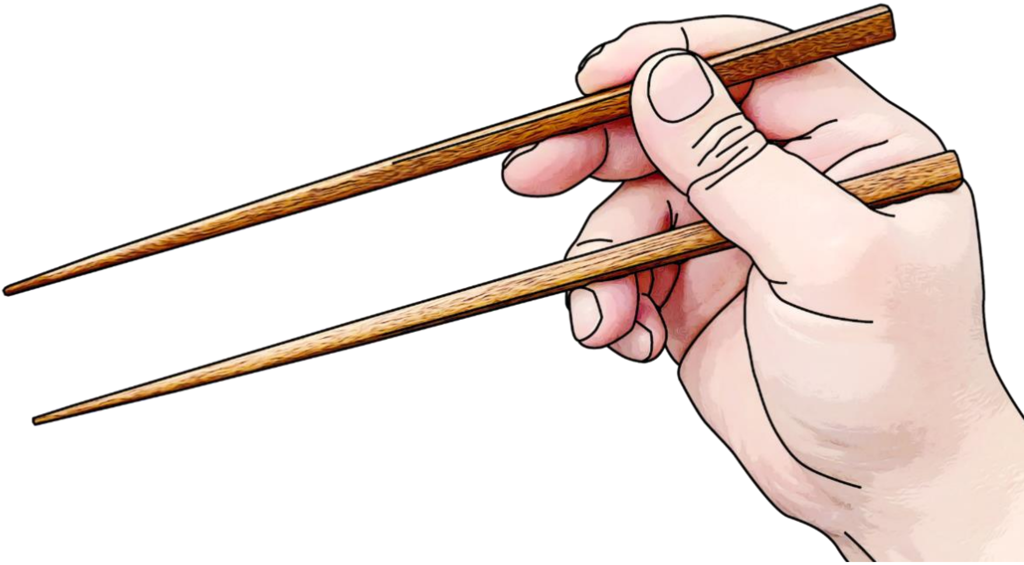
Problem 3
Metallic Chain

There are many more organic than inorganic compounds, both in nature and synthesised artificially. The reason behind this is carbon's mysterious *vis vitalis* tendency to form chains with equally strong consecutive bonds. A few other elements are capable of catenation, like sulfur, nitrogen, or even iodine, albeit to a lower extent. Can such chains be synthesised from metallic elements as well?

Suggest structure and synthesis of a complex or molecule with as many consecutive metal-metal covalent bonds of s- and d-field elements as possible. Please refrain from using metallic clusters and rings. Evaluate the stability of your compound.

Problem 4
Organic Zipper

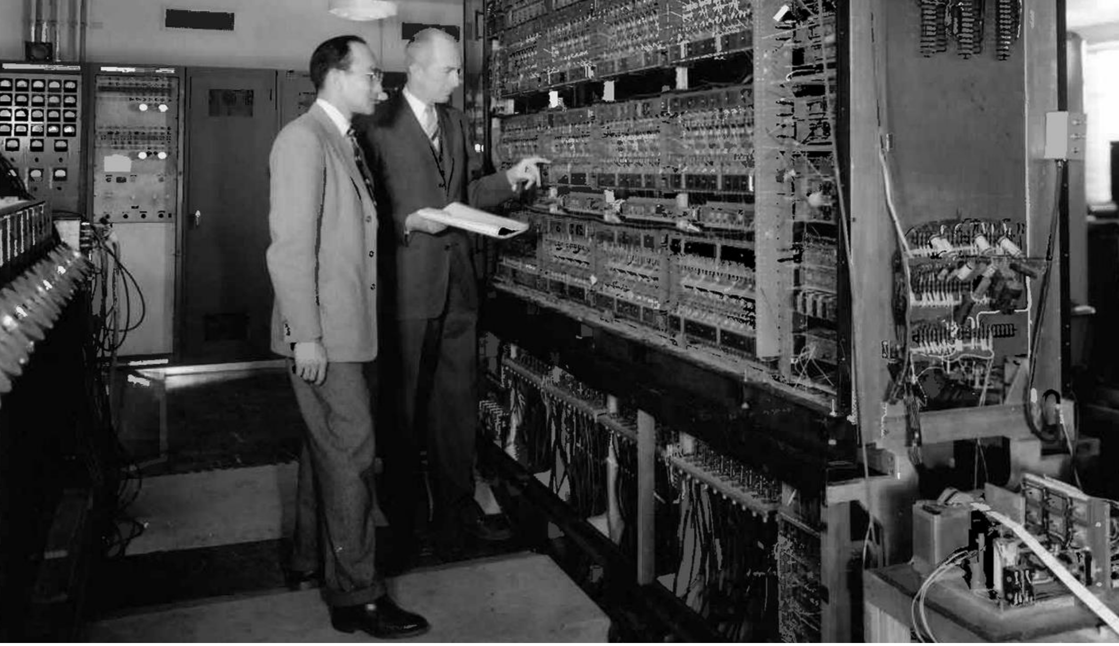
Alkyne zipper and alkene zipper reactions are well-known chemical reactions. For example, the alkyne zipper is a mechanistically simple yet unique reaction, in which an internal alkyne is converted to a terminal one, based on the very different acidity of the starting material and the product. Could you design a zipper reaction for another functional group? Describe your reaction's mechanism, driving force, limitations, functional group tolerance, and potential uses. Your reaction should be a novel, previously undescribed zipper!



Problem 5
Mushrooms Chopsticks

Every year thousands of patients visit the accident and emergency after ingesting poisonous mushrooms. Unfortunately, eating toxic mushrooms may result in serious health issues and even death.

Propose a design for a pair of chopsticks whose colour would change when in contact with a trace amount of a poisonous mushroom of your choice. Your mechanism should rely on chemical reactions. Such a design would warn consumers that their food is contaminated with your chosen poisonous mushroom. Sublethal and lethal amounts of the toxin should be able to trigger the change of colour quickly. Describe in detail how you would manufacture such chopsticks and how they would work. Your chopsticks do not need to be reusable (i.e. if the toxin is detected, the chopsticks can be discarded). Your chopstick should, of course, work as ordinary chopsticks and be safe to use when eating.



Problem 6
Analog Computer

Humanity has reached the point in the development of digital computers where the physical constraints of our universe have started becoming a bottleneck. The famous Moore's law, which predicts the number of transistors that can be packed into a certain area, became nothing more than a relic of the past. To keep up with the increasing demands, scientists started looking at a much older concept, the analog computers. The first of its kind was the Antikythera mechanism, followed by multiple others, mostly up until the 1950s to 1970s. However, with the introduction of very large scale integration and neuromorphic computing, they are going through a renaissance.

Your task is to design an analog-mechanical computer on a chemical scale. You can freely choose the problem for which the computer can give solutions, the data acquisition method and the answer's readout.

Problem 7
Willy Wonka’s New Candy

In "*Charlie and the Chocolate Factory*", the Wonka company produces sweets of near-magical quality, like ice cream that never melts. Your task is to add a 'new candy' to his collection!

Propose how you would manufacture this 'new candy' that, when in the mouth, would produce the five tastes (sweet, salty, sour, bitter, umami) successively in any order. The change of taste should be driven by a change of taste-molecules. The ingredients in the 'new candy' must be evenly distributed (no layered candy). Of course, the candy must be safe to eat and have a long shelf-life. You should describe in detail how the tastes will be generated and how you will ensure that the tastes are generated successively (instead of simultaneously). Finally, predict with reason in which order the taste will be produced in your 'new candy'.

Problem 8
Vampire Material

Vampires, creatures from folklore, are very challenging to kill but are vulnerable to sunlight.

Propose a 'vampire material', a solid material that would be as hard as possible, but that will quickly decompose when exposed to sunlight. Describe in detail the synthesis of your material and an estimation of its hardness. You should also describe how your material can be shaped to adopt the form of a container. Finally, you should describe the underlying mechanism allowing your material to decompose quickly when exposed to sunlight. Sunlight should be the trigger (not heat). Your mechanism should mainly rely on a chemical method (not a physical method).

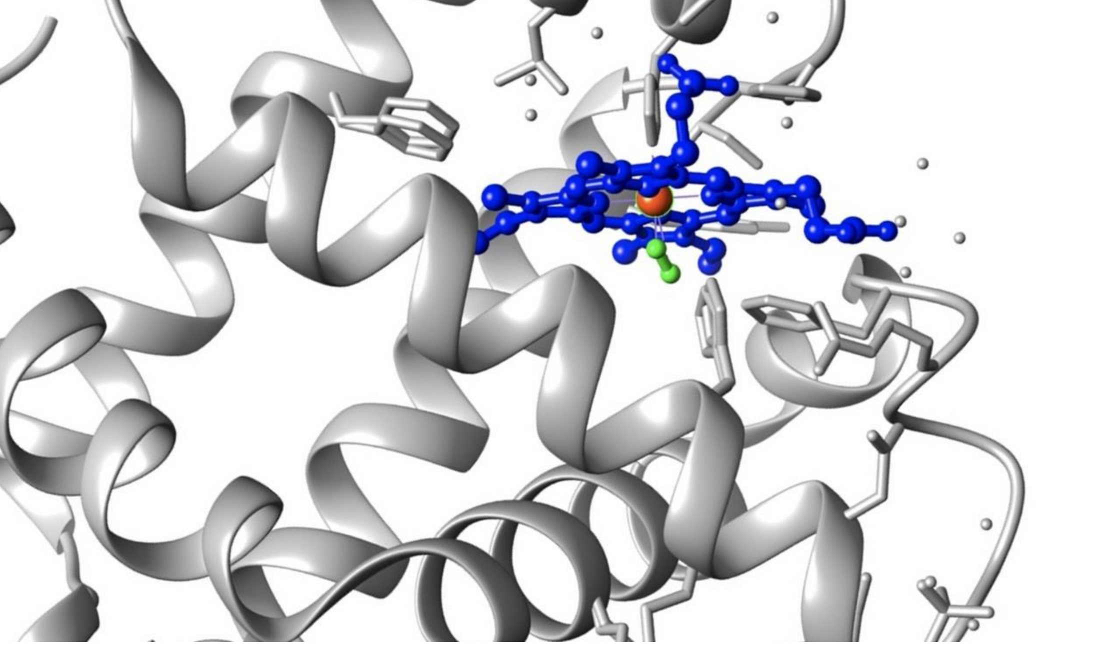
Problem 9
Roman Concrete

Roman concrete, also called *opus caementicium*, is a material that was used in construction in Ancient Rome. Roman concrete was based on hydraulic-setting cement. It is durable due to its incorporation of pozzolanic ash, which prevents cracks from spreading. Further innovative developments in the material, called the concrete revolution, contributed to structurally complicated forms, such as the Pantheon dome, the world's largest and oldest unreinforced concrete dome. Using volcanic ash resulted in a composite that is more stable than modern concrete and can be set underwater. However, it took a longer time to solidify.

Come up with a composition that combines the advantages of both modern and Roman concretes.

Problem 10
Unveiling the Birthplace of Winemaking

Georgia boasts a rich cultural heritage, and one of its most celebrated traditions is winemaking. In fact, the region has been producing wine for over 8,000 years, making it one of the oldest winemaking areas in the world. The country's long history with wine has significantly impacted its culture, and it remains an integral part of Georgian identity. What physical/chemical/instrumental techniques/methods can be used to gather evidence supporting the claim that winemaking originated in Georgia? Name and describe as many methods as possible and explain how they work.



Problem 11
Enzymes Reloaded

Proteins are biological macromolecules generally made up of 20 different amino acids. They can have a wide variety of functions in cells, such as signaling, cell adhesion, maintenance of cell shape and catalysis of biochemical reactions. Those that catalyse reactions are called enzymes, and they often make use of cofactors, since the chemical characteristics of the conventional amino acids would otherwise limit their range of reactions. However, one might imagine an alternate world where proteins evolved without cofactors, and they are more diverse chemically.

Propose a set of 3 'additional' amino acids, which have the potential to make a wide range of cofactors redundant by catalysing reactions or serving as co-substrates, and therefore would enable enzymes to carry out more biochemical reactions on their own. The solution should consider the compatibility of the proposed molecules to the existing set of amino acids, their stability under cellular conditions, as well as their feasibility of synthesis.

Problem 12
Hourglass for Watch-Glass-People

Hourglasses are relatively primitive tools of measuring time, their working mechanism is one of the earliest used by humanity. Nevertheless, we still can find a use for them today in board games or kitchen timers. One advantage of them is that they are fun, or at least they are certainly more entertaining than using a modern stopwatch.

Chemistry on the other hand, has its own clocks, in the form of the very fittingly named clock reactions, where the passing of time is indicated by a sudden change in colour.

So, one might wonder whether combining these two – the working mechanism of an hourglass, and the spectacular effect of a colour change – is possible to create an extraordinary device.

Your task is to design an object that looks and works like an ordinary hourglass (two connected glass bulbs filled with either liquid or solid particles). However, when you turn it, its inner substance should change colour depending on which compartment it is currently in. The colour change must be based on chemistry, its reusability shall be comparable to that of a normal hourglass, and besides the flipping motion of the device no other external energy source should be supplied to the system.