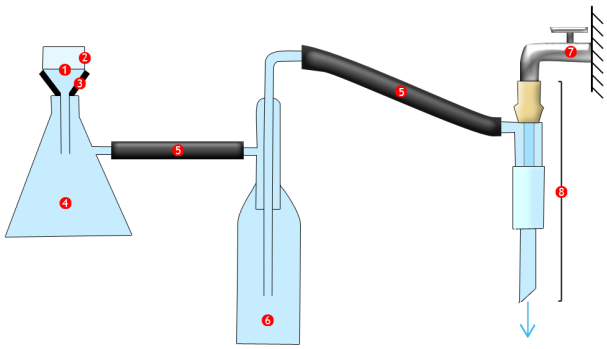
International Chemistry Tournament 2019
Problem Set

Problem 1. Chemical Vacuum Pump



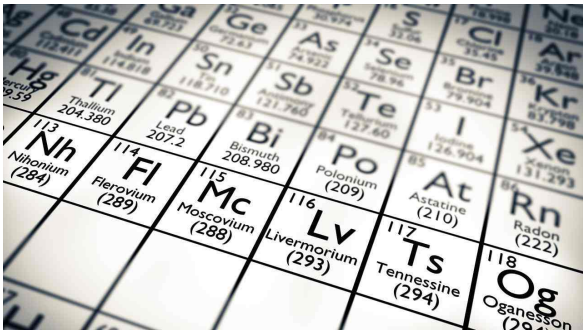
Suggest a system comprised of a sealed vessel with no moving mechanical parts and a mixture of compounds that is capable of creating vacuum under appropriate conditions by chemical reaction. The vessel should be loaded at STP (273 K, 1 bar) and the final pressure should be no more than 1 Pa. Explain how the vessel is loaded and reaction is initiated and estimate the final pressure in the system.

Problem 2. Reduce, Reoxidise, Recycle

Imagine you want to set up the museum of chemistry where different chemical reactions are demonstrated to the public. Suggest a diverse set of reactions for the display bearing in mind that you cannot purchase any reagent except water once you have set up the exhibition.

Hint: use of electrolysis is allowed

Problem 3. The Periodic Law Illustration

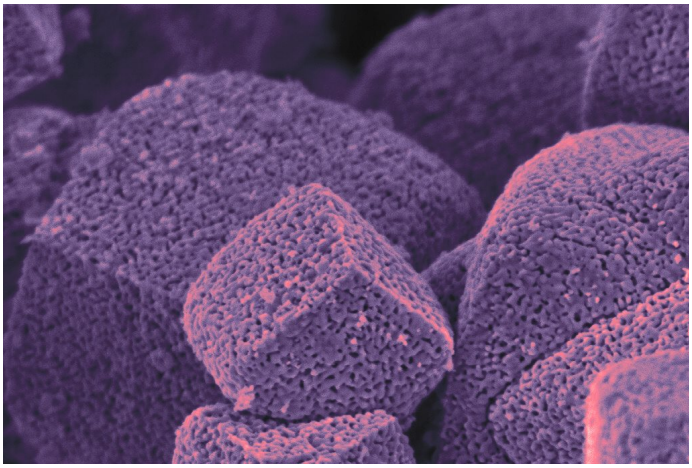


One of the most salient features of the periodic table is, well, periodicity at which element properties change. For example, electronegativity increases as we go across the period. Propose the series of chemical experiments to observe that trend on at least 5 elements in the period.

Problem 4. No Matter How You Spin It?

In Harry Potter book series, an important part of potion preparation is direction of stirring (clockwise or anti-clockwise). Suggest an experiment in which the reaction outcome depends on the way of stirring and explain the underlying mechanism.

Problem 5. Active Metal Nanosponge



Selective dealloying is an efficient method to create materials with high surface area. For example, Raney nickel or recently popular nanosponges (*Nature*, 2001, 410, 450-453) are prepared this way. While straightforward in binary systems, dealloying quickly gets complicated if three or more metals are present.

Assume you have got an alloy or a nanocomposite made up of copper, nickel, silver and gold. Propose a way to remove each of those components while leaving the rest intact. The less side reactions, the better.

Problem 6. Get Low

Oxidation state is an profound concept in modern chemistry which enables us to predict properties of chemical compounds as well as their structural units. We know a lot about the extremely high oxidation states and how those are stabilised. For instance, in IrO_4^+ ion reported to exist in the gas phase formal oxidation state of iridium is +9. Theoretically, there may be relatively stable compounds containing Au^{+11} or Hg^{+12}.

Extremely low oxidation states are also readily accessed. There are examples of compounds which contain an atom in -4 oxidation state such as methane CH_4 and certain metal carbonyl complexes, e.g. $[Cr(CO)_4]^{4-}$. Selected intermetallides featuring Group 13 elements with formal -5 oxidation state were reported as well.

Can compounds with even lower oxidation states exist at normal pressure and 273K? Propose a list of such hypothetical substances.

What are the stabilising factors for the ‘super-low’ oxidation states and how do they contribute to stability of the compounds you have suggested?

Problem 7. Grind It

The colour of a chemical sample may change with particle size. For example, while bulk gold is yellow, its colloidal solutions exhibit a wide range of colours.

Propose a compound or a mixture of compounds which would change its colour at least twice upon grinding in a mortar if the three colours observed must contrast each other. What are the colours you would expect to see and why?

Problem 8. Living with Arsenic

Arsenic is a well-known poison and carcinogen, which is however useful for treating trypanosomiasis (sleeping sickness) and certain cancers. Propose a quantitative assay for arsenic or its soluble compounds in living cells *in vitro*. The method must be non-toxic for the cells and sensitive enough to detect sublethal concentrations.

Problem 9. Chemical Ladder

Extraction is transfer of a solute from one phase (e.g. water) to another (e.g. ether). Usually, two immiscible liquids are used as solvents with chemical interactions being the driving force of the process.

Propose a system with at least four layers of solvents, where a labelled atom of your choice would be transported from the top layer to the bottom or vice versa by means of chemical reactions.

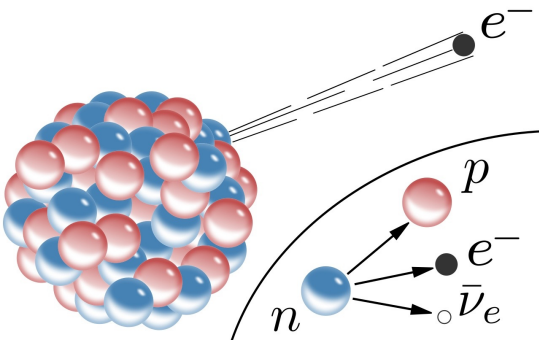
Kolyma River. Credits: Vasily Lebedev / The Polaris Project

Problem 10. Shades of Humic

Natural organic compounds differ in origin: they may come from oil, coal, soils or water. They are studied by elemental analysis (H/C and O/C ratios), NMR, and optical spectroscopy. Furthermore, it is possible to determine the substances semi-quantitatively with the help of modern mass spectrometry methods.

Humins are water-soluble organic molecules which precipitate upon acidification. They are products of breakdown of starch, lignin and other substances. Humins come as complex mixtures which greatly complicates interpretation of integral analysis (NMR, optical spectroscopy) results. Gross formulae are of no use in determining their structure. Nevertheless, humins may significantly influence the surrounding microbiome. Assume you have samples of humins from a river in tropics and a river in Arctic permafrost. Predict how would they differ and why?

Problem 11. Decay and Synthesis



Sometimes it is very hard to obtain a compound by chemical synthesis. The chemists have found a clever way around by using nuclear reactions. For example, perbromate was first obtained from selenate by radioactive decay of selenium atom. Suggest other examples of "nuclear" inorganic or organic syntheses which are hard or impossible to accomplish otherwise.

Credits: Netflix // Stranger Things

Problem 12. Smart Packaging

Behind any spoiled food, there is a chemical reaction. Suggest a smart package for the food product of your choice which would change its colour upon chemical changes in the product. Is it possible to implement your idea by a small upgrade of existing equipment for production of packaging?