International Chemistry Competition

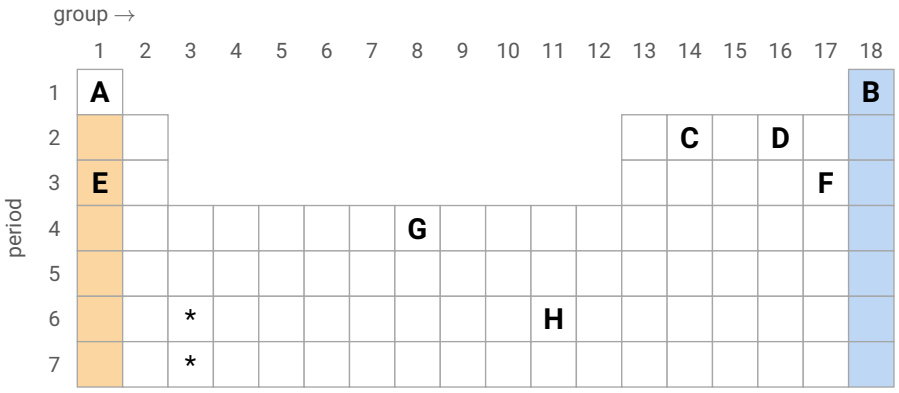
Edition of 2027

Qualification Round

Problem A: A Map of the Elements

In 1869, Dmitri Mendeleev arranged the elements known at the time according to their properties and left gaps for elements that had not been discovered yet. Some of them, such as gallium and germanium, were found a few years later and had almost exactly the properties he had predicted. Today, the periodic table contains 118 elements.

The outline below shows the periodic table with its periods (rows 1 to 7) and groups (columns 1 to 18). Eight cells are marked with the letters A to H, and two of the groups are shaded.



* lanthanoids and actinoids (not shown)

(a) Give the name and the symbol of the elements in the cells A to H.

(b) Name the two shaded groups of elements.

(c) Which of the marked elements A to H are gases at room temperature ($25\,^{\circ}\mathrm{C}$) and normal pressure?

Problem B: A Glass of Water in the Ocean

Molecules are incredibly small, so even everyday amounts of matter contain an enormous number of them.

Imagine that you fill a glass with $250\,\mathrm{mL}$ of pure water before pouring it into the sea. Even this small amount of water consists of an astonishing number of molecules.

Data: density of water $1.00\,\mathrm{g/mL}$; molar mass of water $18.02\,\mathrm{g/mol}$; Avogadro constant $N_A = 6.022 \times 10^{23}\,\mathrm{mol^{-1}}$.

Task: How many water molecules are in the glass? Show your calculation.

Problem C: Four White Powders

Someone has filled four identical jars in a kitchen with white powders and forgotten to label them. The powders are known to be table salt (sodium chloride), sugar (sucrose), baking soda (sodium hydrogen carbonate) and corn starch, but nobody knows which is which. The jars are marked P, Q, R and S.

A friend tests a small sample of each powder in the school laboratory. The observations are:

Test	P	Q	R	S
1. stirred into water	dissolves	dissolves	dissolves	milky, does not dissolve
2. a few drops of vinegar	no change	no change	strong fizzing	no change
3. conductivity of the mixture with water	no	yes	yes	no
4. a drop of brown iodine solution	stays brown	stays brown	stays brown	turns blue-black
5. heated in a metal spoon	melts, turns brown smells of caramel	no change	no melting, releases a gas	slowly turns brown, smells burnt

Vinegar contains acetic acid, $\mathrm{CH_3COOH}$.

(a) Identify the powders P, Q, R and S. For each powder, state which observation is decisive.

(b) Write a balanced equation for the reaction that causes the fizzing in test 2.

(c) The solutions of Q and R conduct electricity, but the solution of P does not, although P also dissolves well. Explain this difference.

Problem D: The Fizz in a Soda Bottle

Sparkling water gets its fizz from carbon dioxide that is dissolved under pressure. In a bottling plant, a $1.50\,\mathrm{L}$ bottle is filled with water and closed under carbon dioxide so that, at $25\,^{\circ}\mathrm{C}$, the partial pressure of $\mathrm{CO_2}$ above the liquid is $3.0\,\mathrm{atm}$.

According to Henry's law, the concentration of a dissolved gas is proportional to its partial pressure p above the liquid:

$$c = K_H \cdot p, \qquad K_H(\mathrm{CO_2},\ 25\,^{\circ}\mathrm{C}) = 3.4 \times 10^{-2}\,\mathrm{mol\,L^{-1}\,atm^{-1}}$$

In air, the partial pressure of $\mathrm{CO_2}$ is $4.2 \times 10^{-4}\,\mathrm{atm}$. Dissolved carbon dioxide makes water slightly acidic:

$$\mathrm{CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)}, \qquad K_a = 4.5 \times 10^{-7}\,\mathrm{mol/L}$$

Data: $M(\mathrm{CO_2}) = 44.01\,\mathrm{g/mol}$; gas constant $R = 0.08206\,\mathrm{L\,atm\,mol^{-1}\,K^{-1}}$. Assume that the concentration of dissolved $\mathrm{CO_2}$ is always the one given by Henry's law, and neglect the small gas space in the bottle and the autoprotolysis of water.

(a) Calculate the mass of $\mathrm{CO_2}$ dissolved in the closed bottle.

(b) After opening, the water slowly comes to equilibrium with the air. What volume of $\mathrm{CO_2}$ escapes at $25\,^{\circ}\mathrm{C}$ and $1.00\,\mathrm{atm}$?

(c) Calculate the pH of the sparkling water right after opening and after it has gone flat.

Problem E: Secret Messages with Invisible Ink

Spies and secret societies have used invisible inks for centuries: a message written with a colourless liquid stays hidden until the paper is warmed up. In this experiment, you will test which liquids from the kitchen work as invisible ink and find out why.

Materials: white printer paper, cotton buds or a fine brush, lemon juice, milk, sugar water (1 teaspoon of sugar dissolved in 3 tablespoons of water), tap water, a towel, a household iron.

Safety: Ask an adult to operate the iron. Never use an open flame or a candle. Stop heating as soon as the writing appears.

Procedure:

1. Divide a sheet of paper into four fields. With a clean cotton bud for each liquid, write a large letter or a short word in each field: one field with lemon juice, one with milk, one with sugar water and one with tap water.
2. Let the paper dry completely (about 15 minutes) and check that the writing is invisible.
3. Place the paper on a towel. The adult irons it on the highest setting without steam, moving the iron slowly, while you watch closely.

(a) Write a protocol: describe what each field looked like after drying and during heating. Which messages appeared, in which colour, and in which order?

(b) Which liquid gave the clearest message? Why does the message written with tap water stay invisible?

(c) Explain the chemistry: why do the parts of the paper covered with lemon juice, milk or sugar water turn brown at a temperature at which the clean paper does not change yet?