General Chemistry Mock Test No. 1

IJSO Theory mock test

This is an IJSO General Chemistry mock test, designed to mimic the style, depth, and difficulty of chemistry questions found in the IJSO. Its aim is to help students strengthen their understanding of the chemistry concepts behind the IJSO and similar competitions.

The questions in this paper were made by the following past IJSO participants (in alphabetical order):

- Alex Jicu (Romania) – Chemistry Mock Test no. 1 Coordinator
- Bianca Buzas (Romania)
- Fillios Memtsoudis (Cyprus)
- Thenura Wickramaratna (Sri Lanka)

No.	Problem	Author	Marks
1	Chemistry in a Tea Shop	Thenura Wickramaratna	3.00
2	Identification of Compounds	Alex Jicu & Bianca Buzas	10.00
3	Mineral Water	Alex Jicu	5.50
4	Chemistry in a Parallel Universe	Alex Jicu	4.25
5	Electrochemical Cells	Fillios Memtsoudis	7.25

In solving the questions, you might need to use the following constants:

Constant	Notation	Value
Acceleration due to gravity	g	$9.8\ ms^{-2}$
Gravitational constant	G	$6.67 \cdot 10^{-11}\ m^3/\ kg \cdot s^2$
Planck's constant	h	$6.62 \cdot 10^{-34}\ J \cdot s$
Elementary charge	e	$1.6 \cdot 10^{-19}\ C$
Speed of light in vacuum	c	$3 \cdot 10^8\ ms^{-1}$
Density of water	ρ	$1000\ kg\ m^{-3}$
Stefan-Boltzmann constant	σ	$5.67 \cdot 10^{-8}\ \frac{W}{m^2K^4}$
Universal gas constant	R	$8.314\ J\ mol^{-1}\ K^{-1}$ $0.0821\ atm\ L\ mol^{-1}\ K^{-1}$
Avogadro's number	N_A	$6.022 \cdot 10^{23}\ mol^{-1}$
Faraday's constant	F	96 500 C/mol
Pi	π	3.14
Electrical permittivity of free space	ε_0	$8.85 \cdot 10^{-12}\ F \cdot m^{-1}$
Magnetic permeability of free space	μ_0	$4\pi \cdot 10^{-7}\ H/m$
Mass of Earth		$5.97 \cdot 10^{24}\ kg$
Mass of Moon		$7.35 \cdot 10^{22}\ kg$
Mass of Sun		$1.99 \cdot 10^{30}\ kg$
Radius of Earth		$6.4 \cdot 10^6\ km$
Radius of Moon		$1.7 \cdot 10^6\ km$
Radius of Sun		$6.96 \cdot 10^8\ km$
Specific heat capacity of water	c_w	$4200\ J/kg \cdot °C$
Average molar mass of air	M	28.9 g/mol

If any other value is provided in the problem, use the value provided, not the one in the table. You can also use the following conversion formulas:

$T\ (K) = t\ (°C) + 273$	$t\ (°F) = \frac{9}{5} t\ (°C) + 32$
$1bar = 1atm = 101\ 000Pa = 760mmHg$	$1u = 1Da = 1.66 \cdot 10^{-27} kg$
$1L = 10^{-3}\ m^3$	$1\ day = 24h$

If needed, you can use the periodic table given bellow:

(Use atomic masses rounded to two decimal places.)

IUPAC Periodic Table of the Elements

Key: atomic number / Symbol / name / abridged standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H hydrogen 1.0080 ± 0.0002																	2 He helium 4.0026 ± 0.0001
3 Li lithium 6.94 ± 0.06	4 Be beryllium 9.0122 ± 0.0001											5 B boron 10.81 ± 0.02	6 C carbon 12.011 ± 0.002	7 N nitrogen 14.007 ± 0.001	8 O oxygen 15.999 ± 0.001	9 F fluorine 18.998 ± 0.001	10 Ne neon 20.180 ± 0.001
11 Na sodium 22.990 ± 0.001	12 Mg magnesium 24.305 ± 0.002											13 Al aluminium 26.982 ± 0.001	14 Si silicon 28.085 ± 0.001	15 P phosphorus 30.974 ± 0.001	16 S sulfur 32.06 ± 0.02	17 Cl chlorine 35.45 ± 0.01	18 Ar argon 39.95 ± 0.16
19 K potassium 39.098 ± 0.001	20 Ca calcium 40.078 ± 0.004	21 Sc scandium 44.956 ± 0.001	22 Ti titanium 47.867 ± 0.001	23 V vanadium 50.942 ± 0.001	24 Cr chromium 51.996 ± 0.001	25 Mn manganese 54.938 ± 0.001	26 Fe iron 55.845 ± 0.002	27 Co cobalt 58.933 ± 0.001	28 Ni nickel 58.693 ± 0.001	29 Cu copper 63.546 ± 0.003	30 Zn zinc 65.38 ± 0.02	31 Ga gallium 69.723 ± 0.001	32 Ge germanium 72.630 ± 0.008	33 As arsenic 74.922 ± 0.001	34 Se selenium 78.971 ± 0.008	35 Br bromine 79.904 ± 0.003	36 Kr krypton 83.798 ± 0.002
37 Rb rubidium 85.468 ± 0.001	38 Sr strontium 87.62 ± 0.01	39 Y yttrium 88.906 ± 0.001	40 Zr zirconium 91.224 ± 0.002	41 Nb niobium 92.906 ± 0.001	42 Mo molybdenum 95.95 ± 0.01	43 Tc technetium [97]	44 Ru ruthenium 101.07 ± 0.02	45 Rh rhodium 102.91 ± 0.01	46 Pd palladium 106.42 ± 0.01	47 Ag silver 107.87 ± 0.01	48 Cd cadmium 112.41 ± 0.01	49 In indium 114.82 ± 0.01	50 Sn tin 118.71 ± 0.01	51 Sb antimony 121.76 ± 0.01	52 Te tellurium 127.60 ± 0.03	53 I iodine 126.90 ± 0.01	54 Xe xenon 131.29 ± 0.01
55 Cs caesium 132.91 ± 0.01	56 Ba barium 137.33 ± 0.01	57-71 lanthanoids	72 Hf hafnium 178.49 ± 0.01	73 Ta tantalum 180.95 ± 0.01	74 W tungsten 183.84 ± 0.01	75 Re rhenium 186.21 ± 0.01	76 Os osmium 190.23 ± 0.03	77 Ir iridium 192.22 ± 0.01	78 Pt platinum 195.08 ± 0.02	79 Au gold 196.97 ± 0.01	80 Hg mercury 200.59 ± 0.01	81 Tl thallium 204.38 ± 0.01	82 Pb lead 207.2 ± 1.1	83 Bi bismuth 208.98 ± 0.01	84 Po polonium [209]	85 At astatine [210]	86 Rn radon [222]
87 Fr francium [223]	88 Ra radium [226]	89-103 actinoids	104 Rf rutherfordium [267]	105 Db dubnium [268]	106 Sg seaborgium [269]	107 Bh bohrium [270]	108 Hs hassium [269]	109 Mt meitnerium [277]	110 Ds darmstadtium [281]	111 Rg roentgenium [282]	112 Cn copernicium [285]	113 Nh nihonium [286]	114 Fl flerovium [290]	115 Mc moscovium [290]	116 Lv livermorium [293]	117 Ts tennessine [294]	118 Og oganesson [294]

57 La lanthanum 138.91 ± 0.01	58 Ce cerium 140.12 ± 0.01	59 Pr praseodymium 140.91 ± 0.01	60 Nd neodymium 144.24 ± 0.01	61 Pm promethium [145]	62 Sm samarium 150.36 ± 0.02	63 Eu europium 151.96 ± 0.01	64 Gd gadolinium 157.25 ± 0.03	65 Tb terbium 158.93 ± 0.01	66 Dy dysprosium 162.50 ± 0.01	67 Ho holmium 164.93 ± 0.01	68 Er erbium 167.26 ± 0.01	69 Tm thulium 168.93 ± 0.01	70 Yb ytterbium 173.05 ± 0.02	71 Lu lutetium 174.97 ± 0.01
89 Ac actinium [227]	90 Th thorium 232.04 ± 0.01	91 Pa protactinium 231.04 ± 0.01	92 U uranium 238.03 ± 0.01	93 Np neptunium [237]	94 Pu plutonium [244]	95 Am americium [243]	96 Cm curium [247]	97 Bk berkelium [247]	98 Cf californium [251]	99 Es einsteinium [252]	100 Fm fermium [257]	101 Md mendelevium [258]	102 No nobelium [259]	103 Lr lawrencium [262]

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For notes and updates to this table, see www.iupac.org. This version is dated 4 May 2022.

Problem 1. Chemistry in a Tea Shop (3.00 points)

At a cozy tea shop nestled in the misty hills of central Sri Lanka, a young science enthusiast named Ravi decides to do a small experiment while helping his grandmother prepare tea for customers.

Part A. Tea Shop Thermochemistry (1.50 points)

She brews the tea in a traditional clay pot, adds a spoonful of sugar, and stirs it gently with a wooden stick. Ravi, curious as ever, notes that the mixture cools slightly after sugar is added, even though the water was just below boiling.

He decides to measure the temperature change. He takes 200 g of water at 95°C, adds 10.0 g of anhydrous glucose ($C_6H_{12}O_6$), and stirs until it dissolves completely. The final temperature drops to 94.8°C.
Assume:

- No heat loss to the surroundings.
- The solutions's heat capacity is equal to that of the water
- All the temperature change is due to the enthalpy of dissolution of glucose.

A1. Calculate the molar enthalpy of solution (H_{sol}) of glucose in kJ/mol based on the observation.

(0.75 points)

When measuring concentrations, one quantity that can be used is the molality of a solution. The molality is defined as the number of moles of solute per mass of solven (usually expressed in mol/kg).
A2. Find the molality of the glucose solution Ravi prepared

(0.25 points)

The physical properties of solutions slightly vary compared to those of pure solvents. One physical property that changes is the freezing point – a phenomenon known as freezing point depression. The decrease in the freezing point is given by $\Delta T = K_f m$, where m is the molality of the solution and K_f is the cryoscopic constant of the solvent.

A3. If Ravi's solution freezes at -0.52℃, find the cryoscopic constant of water.

(0.50 points)

Part B. The Chemistry of Acidity in Tea (0.50 points)

One afternoon, a tourist at Ravi's grandmother's shop complains that her tea tastes "too sour." Curious, Ravi decides to measure the pH of different types of tea. He finds the following:

- Freshly brewed black tea: pH 5.1
- Green tea: pH 6.2
- Lemon tea: pH 3.8

He then reads that tannic acid, a weak organic acid found in tea leaves, is partially responsible for the acidic taste. He learns that a typical black tea infusion contains about 0.0010 mol/L of tannic acid, which only partially ionizes in water.

B1. Assuming tannic acid is a monoprotic weak acid with a Ka value of 4×10^{-6}, calculate the pH of the solution at 0.0010 mol/L.

(0.50 points)

Part C. Tea Sugar Sweetening (1.00 points)

Ravi wants to sweeten 1.5 L of freshly brewed tea by adding sucrose (table sugar, ($C_{12}H_{22}O_{11}$). He wants the tea to have a sugar concentration equivalent to 6.0% by mass. The density of the tea is approximately 1.00 g/mL

C1. Calculate the mass of sugar Ravi needs to add.

(0.30 points)

C2. If Ravi adds only 50 g of sugar, what will be the molar concentration of the sugar in the tea?

(0.70 points)

Problem 2. Identification of Compounds (10.00 points)

In inorganic chemistry, identifying chemical compounds based on only a limited number of facts known about them is a very important skill. In this problem you will have to determine the formulas of a number of chemical compounds, in different contexts.

Part A. Formula of a Salt (3.35 points)

An unknown ionic binary solid (containing two elements) **A** can react with simple gaseous substance **B** (reaction 1). It is known about substance **B** that its atoms are those with the highest electronegativity out of all the elements.

Upon the completion of reaction 1, a yellow-green gas **C** with a pungent smell is released.

A sample of solid **A**, weighing 2 grams, is dissolved in 100mL of water. Using a pipette, 10mL of this solution are taken and mixed with a small amount of potassium chromate (K_2CrO_4).

The 10mL of the solution are titrated with a 0.1M solution of solid **D** (reaction 2), until the endpoint is reached (reaction 3). In the titration process, 34.2mL of substance **D** are used.

It is known that substance **D** has the following mass composition: 63.16% silver, 8.19% nitrogen and the rest oxygen.

A1. Identify substances **A**, **B**, **C** and **D**

(1.80 points)

A2. Write the balanced equations of reactions 1, 2 and 3

(0.75 points)

A3. For each of the substances specify if it's ionic, covalent polar or covalent nonpolar

(0.60 points)

Part B. Substances Taking Part in a Redox Reaction (6.65 points)

Consider the following unbalanced chemical reaction:

$$A + B + C \rightarrow D + E + F + G$$

The following facts about the involved substances are known:

- A is a chloride of metal D in divalent form
- B is a disinfectant whose decomposition is catalyzed by MnO_2
- C is the hydroxide of the alkali metal with two p subshells in its electronic structure
- D is the only liquid metal in standard conditions
- E is one of the main gases in the Earth's atmosphere
- G is a common liquid, essential for life

B1. Write the chemical formulas of compounds A-G

(2.75 points)

B2. Write the balanced equation of the reaction and the equations of the oxidation and reduction half-reactions

(1.50 points)

If you weren't able to balance the equation, for the following questions consider all molar ratios between all products and reactants are 1:1.

For obtaining 5.025g of metal D in safe laboratory conditions, scientists want to prepare a solution of compound B starting from a 1L solution that contains $2.71 \cdot 10^{23}$ B molecules, called solution S1. They take 10mL of solution S1 and dilute it until a 0.1M solution (S2) is formed.

B3. What mass of water ($\rho = 1\,\frac{g}{cm^3}$) is used to dilute the 10mL of solution S1 to obtain the required solution S2.

(1.00 points)

B4. If the reaction has a 85% yield, what volume of solution S2 is used to obtain the desired amount of metal D.

(0.70 points)

B5. For the experiment described, 100mL of solution S3 containing substance C were stoichiometrically necessary. Find the pH of solution S3.

(0.70 points)

Problem 3. Mineral Water (5.50 points)

A sample of a mineral water, containing calcium and phosphorus is analyzed using different analytical techniques.

A. In the following text, choose the right word from each pair of bolded words:

> The solution to be analyzed is a **supersaturated/saturated** solution, a metastable (unstable) state, in which the solute concentration exceeds the theoretical limit and any small disturbance may cause it to **crystalize/dissolve**. To get the solution to a state where this is no longer a problem, the solution is **heated/cooled** and all analysis is performed at this temperature.

(0.30 points)

You can consider that the temperature range is small enough to be able to consider all constants equal to their values at 25°C. The following constants are given:

Acid-base equilibria:

Ionization product of water	K_W	1.00×10^{-14}
First acidity exponent of phosphoric acid	$pK_{a1}(H_3PO_4)$	2.15
Second acidity exponent of phosphoric acid	$pK_{a2}(H_3PO_4)$	7.20
Third acidity exponent of phosphoric acid	$pK_{a3}(H_3PO_4)$	12.35

Solubility products:

$Ca(OH)_2$	5.5×10^{-6}
$Ca_3(PO_4)_2$	1.0×10^{-25}
$CaHPO_4$	2.0×10^{-7}
$Ca(H_2PO_4)_2$	$\gg 1$ (perfectly soluble)

Adding a small amount of an acid-base indicator to a sample of the solution and using spectrophotometric techniques, the pH of the water was found to be weakly alkaline with $pH = 7.12$

The concentration of calcium in this solution was found to be $c = 5 \times 10^{-4} M$

B. Choose which technique could have been used for the determination of calcium:

Acid-base titration (based on the acid-base properties of calcium hydroxide)	
Redox titration (based on transformations between oxidation states of calcium)	
Complexonometric titration (based on the formation of a calcium complex)	
Argentometry (based on the formation of a silver-calcium precipitate)	

(0.20 points)

Finding the total concentration of phosphorus was done using precipitation with ammonium molybdate. This yields ammonium phosphomolybdate $(NH_4)_3[PMo_{12}O_{40}]$. All the phosphorus in solution is now found as ammonium phosphomolybdate. Precipitation of phosphorus from 10mL of solution (with 100% yield) gives 16.89mg of ammonium phosphomolybdate.

C. Calculate the total molar concentration of phosphorus in the solution.

(0.75 points)

D. Using the acidity constants formulas, find the expressions of all phosphate system ions (dihydrogen phosphate, monohydrogen phosphate and neutral phosphate) in terms of acidity constants, the concentration of protons and the concentration of phosphoric acid.

(1.00 points)

E. Using results in parts C and D, find the values of the molar concentrations of phosphoric acid, dihydrogen phosphate, monohydrogen phosphate and neutral phosphate.

(1.50 points)

F. Through calculations, determine which of the following compounds will precipitate when the solution is brought back to 25°C:

$Ca(OH)_2$	
$Ca_3(PO_4)_2$	
$CaHPO_4$	

(1.75 points)

Problem 4. Chemistry in a Parallel Universe (4.25 points)

When dealing with electron structures, one very important rule is the Pauli exclusion principle, which states: “No identical electrons can occupy the same quantum state (orbitals)”. Despite this, it is known that each orbital can be filled with two electrons. That is because they are not identical – they differ because of a quantity called spin. Each electron can have spin up or spin down, which makes two possible kinds of electrons able to occupy the same quantum state.

Let’s now imagine another Universe in which, all known rules related to electron shells still hold, but now electrons can have three kinds of spin – spin up, spin null and spin down.

When drawing electron structures, a line with no arrowhead (|) may be used to represent spin null electrons.

Unless stated otherwise, the following questions refer to elements in this parallel imaginary Universe.

Part A. Stable Elements (0.50 points)

Write the chemical symbol of the element which is the lightest element with a stable valance shell structure.

(0.50 points)

Part B. Properties of Aluminum (1.30 points)

Because of these new electron structures, all known chemical properties of elements change.

B1. Using the given rules, draw the electron structure of aluminum.

(1.00 points)

B2. Using the drawn electron structure, what element **from our Universe** does aluminum n in the imaginary Universe resemble the most? Tick the right answer.

Neon	
Calcium	
Chlorine	
Sulfur	

(0.30 points)

Part C. More Chemical Properties (1.20 points)

C1. Give an example of an element which, in this imaginary Universe, would be a monovalent metal

(0.60 points)

C2. Give an example of an element, which, on this imaginary Universe, would be a divalent nonmetal

(0.60 points)

Part D. The Periodic Table (1.25 points)

In our Universe, the heaviest known element is oganesson, which is a noble gas with a full 8p subshell. Let's suppose that in the imaginary Universe, the heaviest known element is also the one which has a full 7p subshell.

D1. How many periods and how many groups does the periodic table of the imaginary Universe have?

Hint: In the imaginary periodic table, the f-block is added as an extension under the table just like in our Universe

(0.75 points)

D2. How many elements are there in the s-block of the periodic table in the imaginary Universe?

(0.50 points)

Problem 5. Electrochemical Cells (7.25 points)

In electrochemical cells, redox reactions occur. Some electrochemical cells present commercial interest.

The following table contains some redox half-reactions and their standard potentials E^0.

Half Reaction	Standard Potential (V)
$Zn^{2+}_{(aq)} + 2e^- \rightarrow Zn_{(s)}$	-0.76
$Ag_2O_{(s)} + 2H^+_{(aq)} + 2e^- \rightarrow 2Ag_{(s)} + H_2O_{(l)}$	+0.34
$O_{2\,(g)} + 4H^+_{(aq)} + 4e^- \rightarrow 2H_2O_{(l)}$	+1.23
$F_{2(g)} + 2e^- \rightarrow 2F^-_{(aq)}$	+2.87

Part A. Redox Reactions (0.75 points)

Using the data from the above table:

A1. Write the strongest reducing agent among those in the table.

(0.25 points)

A2. Write the chemical reaction of fluorine and water.

(0.50 points)

Part B. A Simple Electrochemical Cell (1.00 points)

An electrochemical cell can be constructed using a zinc electrode and another made of silver in contact with silver oxide. This cell is used in electronic devices.

For the above element:

B1. Write its symbol.

(0.50 points)

B2. Calculate the standard cell potential, E^0_{cell}

(0.50 points)

Part C. More Analysis of a Lead Battery (3.60 points)

The standard potential of a lead-oxide electrochemical cell is $E^0 = +2.15V$. The redox reaction taking place is:

$$PbO_{2\,(s)} + Pb_{(s)} + 2H^+_{(aq)} + 2HSO^-_{4\,(aq)} \rightarrow 2PbSO_{4\,(s)} + 2H_2O_{(l)}$$

Below are the half-cell reactions occurring at the electrodes of the cell:

(1) $PbO_{2\,(s)} + 3H^+_{(aq)} + HSO^-_{4\,(aq)} + 2e^- \rightarrow PbSO_{4\,(s)} + 2H_2O_{(l)}$ $\quad E^0_1 = +1.69V$

(2) $PbSO_{4\,(s)} + H^+_{(aq)} + 2e^- \rightarrow Pb_{(s)} + HSO^-_{4\,(aq)}$ $\quad E^0_2 = x$

C1. Calculate the potential of reaction (2).

(0.65 points)

C2. After some time of discharge, the concentration of H^+ ions near the Pb electrode decreases from 1.0 M to 0.80 M. Assuming the rate law for the cell reaction is:

$\text{rate} = k \times [H^+]^n$ with $k = 2.5 \times 10^{-3}$ (SI unit)

calculate:

(a) The rate of reaction at the beginning (when $[H^+] = 1.0$ M)

(0.40 points)

(b) The order n of the reaction, if it's known that the rate at 0.80 M is 64% of the initial rate.

(1.00 points)

(c) The rate of reaction when $[H^+] = 0.80$ M

(0.20 points)

The integrated rate laws for some values of n are given:

If n = 1, $[H^+] = [H^+]_0 e^{-kt}$

If n ≠ 1, $\frac{1}{[H^+]^{n-1}} = \frac{1}{[H^+]_0^{n-1}} + (n-1)kt$

C3. Based on your result from C2. estimate how long it will take for $[H^+]$ to fall from 1.0 M to 0.50 M. Assume no reverse reaction occurs and the rate law remains valid.

(0.60 points)

C4. Use the following standard enthalpies of formation (ΔH_f^0):

- PbO_2(s): $\Delta H_f^0 = -277$ kJ/mol
- $PbSO_4$(s): $\Delta H_f^0 = -920$ kJ/mol
- Pb(s): $\Delta H_f^0 = 0$ kJ/mol
- H_2O(l): $\Delta H_f^0 = -286$ kJ/mol
- H^+(aq): $\Delta H_f^0 = 0$ kJ/mol
- HSO_4^-(aq): $\Delta H_f^0 = -886$ kJ/mol

Consider the overall reaction in the electrochemical cell:

$$PbO_{2\,(s)} + Pb_{(s)} + 2H^+_{(aq)} + 2HSO^-_{4\,(aq)} \rightarrow 2PbSO_{4\,(s)} + 2H_2O_{(l)}$$

Calculate the overall enthalpy change ΔH^0_{cell}

(0.75 points)

Part D. Mass Changes in the Battery (1.90 points)

Consider that the reaction from the cell in part C is now taking place in one flask – it's no longer separated into two half-cells to create a cell. If 10^{-3}mol of electrons are transferred:

D1. Using the stoichiometry of the reaction, find the mass of lead that was oxidized

(0.40 points)

D2. Calculate by how much the total mass (mg) of the solid phase increases

(0.75 points)

D3. If the actual measured increase of the total mass of the solid phase is 42mg, find the mass of lead sulfate that dissolved in water

(0.25 points)

D4. If the reaction is performed in a 1L aqueous solution, find the solubility (mg/L) of lead sulphate

(0.30 points)