I. MULTIPLE-CHOICE QUESTIONS WITH SINGLE CORRECT ANSWER

(Answer by choosing only one of the options (A), (B), (C) or (D))

Periodic table with some essential data is given at the end of the test!

1. In a closed container, under certain conditions, the molecules of NOBr decompose into NO and Br_2 molecules, according to the equation:

$$2\ NOBr(g) \rightleftarrows 2\ NO(g) + Br_2(g)$$

$$\Delta_r H = +16{,}3\ kJ\ mol^{-1}$$

Which change(s) will lead to an increase in the amount of NO within this equilibrium?

I. Temperature increase.
II. Temperature decrease.

(A) Only I.
(B) Only II.
(C) I and II.
(D) Neither one of them.

2. For the majority of the chemical reactions, upon reaching equilibrium, the Gibbs energy has the value:
A) greater than 0 kJ
B) less than 0 kJ
C) equal to 0 kJ
D) none of the provided answers is correct.

3. Which combination of HCl and NaOH solutions will produce the greatest temperature change upon mixing?
(A) 50 mL - 1mol/dm^3 HCl with 50 mL - 1mol/dm^3 NaOH
(B) 50 mL - 2 mol/dm^3 HCl with 50 mL - 2 mol/dm^3 NaOH
(C) 100 mL - 1 mol/dm^3 HCl with 50 mL - 2 mol/dm^3 NaOH
(D) 100 mL - 1 mol/dm^3 HCl with 100 mL - 1mol/dm^3 NaOH

4. In what order should the molecules O_2, H_2O, OF_2, and H_2O_2 be arranged to follow the trend of increasing oxidation numbers of the oxygen atom?
(A) O_2 , H_2O, OF_2 , H_2O_2
(B) H_2O, H_2O_2 , O_2 , OF_2
(C) H_2O_2 , O_2 , H_2O, OF_2
(D) OF_2, O_2 , H_2O_2 , H_2O

5. Estimate the pH value of a KOH solution prepared by dissolving one small spoonful of solid KOH in approximately 100 mL of water.
(A) pH = 1.40
(B) pH = 2.50
(C) pH = 8.40
(D) pH = 12.40

6. Which of the solutions prepared by dissolving the salts listed below, will exhibit the strongest basic character, assuming the concentration of each salt in the solutions is 0.1 mol/dm^3?
(A) KNO_3
(B) $NaNO_2$
(C) NH_4Cl
(D) $MgCl_2$

7. Which of the reactions given by the chemical equations, will give a gaseous product?
(A) $HNO_3(aq) + Cu(s)$
(B) $HCl(aq) + Zn(s)$
(C) $HNO_3(aq) + Na_2CO_3$
(D) All of the above listed.

8. The catalyst accelerates the chemical reaction by:
(A) shifting the equilibrium.
(B) increasing the activation energy.
(C) reducing the reaction enthalpy.
(D) providing an alternative reaction pathway.

9. In what order does the entropy value increase at 25 °C?
(A) Na(s), NaCl(s), $Cl_2(g)$
(B) NaCl(s), $Cl_2(g)$, Na(s)
(C) $Cl_2(g)$, NaCl(s), Na(s)
(D) Na(s), $Cl_2(g)$, NaCl(s)

10. Which of the following statements about chemical reactions is **incorrect**?

(A) A chemical reaction proceeds until, at least one of the reactants is fully consumed.

(B) In the case of a reversible reaction, at the stage of chemical equilibrium, the rate of the forward reaction equals the rate of the backward reaction.

(C) A chemical reaction proceeds until both the limiting reactant and the excess reactant are completely consumed.

(D) All of the above statements are incorrect.

11. Which of the following statements is **incorrect**?

(A) For the reversible reactions, measurable quantities of all participants in the reaction are present, except at the moment $t = 0$.

(B) In reversible reactions, the extent of the reaction does not reach its maximum value, $\xi \neq \xi_{max}$.

(C) In reversible reactions, the forward and backward reactions proceed at the same rate at every instant of time.

(D) The formation of a stable complex indicates that the reaction is irreversible.

12. The relationship between the rate of a chemical reaction and the rate of conversion can be represented by the equation:

(A) $\upsilon = J / V$

(B) $J = \upsilon / V$

(C) $\upsilon = J V$

(D) $J = V / \upsilon$

13. The units of measurement for the quantities: the rate of a chemical reaction and the rate of change in the concentration of reactant *i*, respectively, are:

(A) mol L^{-1} s^{-1} and mol s^{-1}

(B) mol s^{-1} and mol L^{-1} s^{-1}

(C) mol L^{-1} s^{-1} and mol L^{-1} s^{-1}

(D) mol s^{-1} and mol s^{-1}

14. Condensation reactions may release molecules of:

(A) water;

(B) hydrogensulfide;

(C) ammonia;

(D) all of the above are possible.

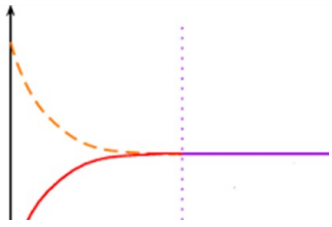
15. What should be displayed on the *x*-axis and *y*-axis of the graph describing dynamic equilibrium in the reaction?

(A) Time and energy.

(B) Time and rate of reaction.

(C) Rate of reaction and time.

(D) Concentration and time.



II. TASKS/PROBLEMS

(Write down the solution procedure and the answer in the designated place)

1. The equilibrium system $H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g)$ was analyzed, and at the state of equilibrium, 1.25 mol of H_2, 0.40 mol of I_2, and 0.50 mol of HI were detected. The temperature of the reaction vessel was adjusted to a value at which the equilibrium constant K_c is three times larger. What is the mass of HI present in the vessel under the new temperature conditions?

$$K_c = \frac{c_e(\mathrm{HI})^2}{c_e(\mathrm{H_2})c_e(\mathrm{I_2})} = \frac{\frac{n_e(\mathrm{HI})^2}{V_{\text{сад}}{}^2}}{\frac{n_e(\mathrm{H_2})}{V_{\text{сад}}}\frac{n_e(\mathrm{I_2})}{V_{\text{сад}}}} = \frac{n_e(\mathrm{HI})^2}{n_e(\mathrm{H_2})n_e(\mathrm{I_2})}$$

$$K_c = \frac{(0{,}50\ \mathrm{mol})^2}{1{,}25\ \mathrm{mol} \cdot 0{,}40\ \mathrm{mol}} = 0{,}50$$

$$K_{\text{нова}} = \frac{c_{\text{нова}}(\mathrm{HI})^2}{c_{\text{нова}}(\mathrm{H_2})c_{\text{нова}}(\mathrm{I_2})} = \frac{\frac{n_{\text{ново}}(\mathrm{HI})^2}{V_{\text{сад}}{}^2}}{\frac{n_{\text{ново}}(\mathrm{H_2})}{V_{\text{сад}}}\frac{n_{\text{ново}}(\mathrm{I_2})}{V_{\text{сад}}}} = \frac{n_{\text{ново}}(\mathrm{HI})^2}{n_{\text{ново}}(\mathrm{H_2})n_{\text{ново}}(\mathrm{I_2})} = 3K_{\text{почетна}}$$

$$= 1{,}50$$

$$n_{\text{ново}}(\mathrm{HI}) = n_{\text{почетно}}(\mathrm{HI}) + n_{\text{генерирано}}(\mathrm{HI}) = n_e(\mathrm{HI}) + 2x = 0{,}50\ \mathrm{mol} + 2x$$
$$n_{\text{ново}}(\mathrm{H_2}) = n_{\text{почетно}}(\mathrm{H_2}) - n_{\text{изреагирано}}(\mathrm{H_2}) = n_e(\mathrm{H_2}) - x = 1{,}25\ \mathrm{mol} - x$$
$$n_{\text{ново}}(\mathrm{I_2}) = n_{\text{почетно}}(\mathrm{I_2}) - n_{\text{изреагирано}}(\mathrm{I_2}) = n_e(\mathrm{I_2}) - x = 0{,}40\ \mathrm{mol} - x$$

$$1{,}50 = \frac{(0{,}50\ \mathrm{mol} + 2x)^2}{(1{,}25\ \mathrm{mol} - x)(0{,}40\ \mathrm{mol} - x)}$$

$$2{,}50x^2 + 4{,}475x - 0{,}50 = 0$$

$n_{\text{ново}}(\mathrm{HI})$:

$$n_{\text{ново}}(\mathrm{HI}) = 0{,}50\ \mathrm{mol} + 2x = 0{,}50\ \mathrm{mol} + 0{,}210\ \mathrm{mol} = 0{,}71\ \mathrm{mol}$$
$$m(\mathrm{HI}) = n_{\text{ново}}(\mathrm{HI})M(\mathrm{HI}) = 0{,}71\ \mathrm{mol} \cdot 127{,}9\frac{\mathrm{g}}{\mathrm{mol}} = 90{,}8\ \mathrm{g}$$

2. A 240 mg mixture of $FeSO_4 \cdot 7H_2O$ and $SnSO_4$ was dissolved in water to a final volume of 20 mL and acidified with a small amount of sulfuric acid. For the complete oxidation of Fe^{2+} and Sn^{2+} ions, exactly 9 mL of potassium permanganate solution with a concentration of 0.0332 mol/dm^3 was required. Knowing that the mixture contains only $FeSO_4 \cdot 7H_2O$ and $SnSO_4$, calculate the mass fraction of the iron salt in the mixture.

$$FeSO_4 + H_2SO_4 + KMnO_4 \rightarrow Fe_2(SO_4)_3 + MnSO_4 + K_2SO_4 + H_2O$$

$$SnSO_4 + H_2SO_4 + KMnO_4 \rightarrow Sn(SO_4)_2 + MnSO_4 + K_2SO_4 + H_2O$$

$$10\overset{+2}{\text{FeSO}_4} + 8\text{H}_2\text{SO}_4 + 2\overset{+7}{\text{KMnO}_4} \rightarrow 5\overset{+3}{\text{Fe}_2(\text{SO}_4)_3} + 2\overset{+2}{\text{MnSO}_4} + \text{K}_2\text{SO}_4 + 8\text{H}_2\text{O}$$

$$5\overset{+2}{\text{SnSO}_4} + 8\text{H}_2\text{SO}_4 + 2\overset{+7}{\text{KMnO}_4} \rightarrow 5\overset{+4}{\text{Sn}(\text{SO}_4)_2} + 2\overset{+2}{\text{MnSO}_4} + \text{K}_2\text{SO}_4 + 8\text{H}_2\text{O}$$

$$n(\text{KMnO}_4) = n(\text{KMnO}_4)_{\text{за Fe}} + n(\text{KMnO}_4)_{\text{за Sn}}$$

$$n(\text{KMnO}_4) : n(\text{FeSO}_4) = 2 : 10 = 1 : 5$$

$$\Rightarrow \quad n(\text{KMnO}_4)_{\text{за Fe}} = \frac{1}{5} n(\text{FeSO}_4)$$

$$n(\text{KMnO}_4) : n(\text{SnSO}_4) = 2 : 5$$

$$\Rightarrow \quad n(\text{KMnO}_4)_{\text{за Sn}} = \frac{2}{5} n(\text{SnSO}_4)$$

$$n(\text{KMnO}_4) = \frac{1}{5} n(\text{FeSO}_4) + \frac{2}{5} n(\text{SnSO}_4)$$

$$n(\text{KMnO}_4) = \frac{1}{5} n(\text{FeSO}_4 \cdot 7\text{H}_2\text{O}) + \frac{2}{5} n(\text{SnSO}_4)$$

$$c(\text{KMnO}_4)V(\text{KMnO}_4) = \frac{1}{5}\frac{m(\text{FeSO}_4 \cdot 7\text{H}_2\text{O})}{\text{M}(\text{FeSO}_4 \cdot 7\text{H}_2\text{O})} + \frac{2}{5}\frac{m(\text{SnSO}_4)}{M(\text{SnSO}_4)}$$

$$c(\text{KMnO}_4)V(\text{KMnO}_4) = \frac{1}{5}\frac{m(\text{FeSO}_4 \cdot 7\text{H}_2\text{O})}{\text{M}(\text{FeSO}_4 \cdot 7\text{H}_2\text{O})} + \frac{2}{5}\frac{m(\text{смеса}) - m(\text{FeSO}_4 \cdot 7\text{H}_2\text{O})}{M(\text{SnSO}_4)}$$

$$w(\text{FeSO}_4 \cdot 7\text{H}_2\text{O}) = \frac{m(\text{FeSO}_4 \cdot 7\text{H}_2\text{O})}{m(\text{смеса})} = \frac{129{,}6\ \text{mg}}{240\ \text{mg}} = 0{,}539 = 53{,}9\ \%$$

3. The autoprotolysis of water is different at various temperatures. Accordingly, there are a lot of different tables that specify the value of the ionic product of water at different temperatures. For example, the value of K_w at a temperature of 10 °C is $2.90 \cdot 10^{-15}$ mol^2/dm^6.

   (A) Write down the equation for the autoprotolysis of water, highlighting the aggregate state or solution state of the participants in the reaction, as is conventionally done in chemical equations.

$$2\text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{OH}^-(aq)$$

(This reaction is reversible. This answer will not be accepted: $2\text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{OH}^-(aq)$.)

(B) Knowing that the value of the ionic product of water at 25 °C is exactly 10^{-14} mol^2/dm^6, answer whether the autoprotolysis of water is endothermic or exothermic and explain your reasoning.

As the temperature increases (in this case, from 10 °C to 25 °C), the equilibrium constant also rises. This necessarily implies that the temperature increase results in the production of additional amounts of the products, confirming that the reaction must be endothermic.

(C) Calculate the pH value of pure water cooled to 10 °C?

$$c_e(H_3O^+) = c_e(OH^-)$$

$$K_w = c_e(H_3O^+) \cdot c_e(OH^-) = c_e(H_3O^+)^2$$

$$c_e(H_3O^+) = \sqrt{K_w} = 5{,}38 \cdot 10^{-8}\ \text{mol/dm}^3$$

$$\text{pH} = -\log_{10}(5{,}38 \cdot 10^{-8}) = -(-7{,}27) = 7{,}27$$

(D) An aqueous solution at 10 °C has a pH of 7. What is the nature of the solution (acidic, basic or neutral)? Why?

The solution is acidic because pH < 7.27, meaning that $c_e(H_3O^+) > c_e(OH^-)$.

1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 181.0	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.0	89 **Ac** 227.0	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Ds** (281)	111 **Uuu** (272)	112 **Uub** (285)	113 **Uut** (284)	114 **Uuq** (289)	115 **Uup** (288)			

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)