2024 Academic Challenge

CHEMISTRY TEST – SECTIONAL

Chemistry Test Production Team

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GENERAL DIRECTIONS

Please read the following instructions carefully. This is a timed test; any instructions from the test supervisor should be followed promptly.

The test supervisor will give instructions for filling in any necessary information on the answer sheet. Most Academic Challenge sites will ask you to indicate your answer to each question by marking an oval that corresponds to the correct answer for that question. One oval should be marked to answer each question. Multiple ovals will automatically be graded as an incorrect answer.

Be sure ovals are marked as ● , not ⊙ , ⊕ , ◑ , etc.

If you wish to change an answer, erase your first mark completely before marking your new choice.

You are advised to use your time effectively and to work as rapidly as you can without losing accuracy. Do not waste your time on questions that seem too difficult for you. Go on to the other questions, and then come back to the difficult ones later if time remains.

Time: 40 Minutes Number of Questions: 40

DO NOT OPEN TEST BOOKLET UNTIL YOU ARE TOLD TO DO SO!

Periodic Table of the Elements

1 IA																17 VIIA	18 VIIIA
1 **H** 1.0079	2 IIA											13 IIIA	14 IVA	15 VA	16 VIA	1 **H** 1.0079	2 **He** 4.0026
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.179
11 **Na** 22.990	12 **Mg** 24.305	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 ←	9 VIIIB	10 →	11 IB	12 IIB	13 **Al** 26.982	14 **Si** 28.086	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.08	21 **Sc** 44.956	22 **Ti** 47.90	23 **V** 50.941	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.847	27 **Co** 58.933	28 **Ni** 58.70	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.22	41 **Nb** 92.906	42 **Mo** 95.94	43 **Tc** [97.91]	44 **Ru** 101.07	45 **Rh** 102.905	46 **Pd** 106.4	47 **Ag** 107.868	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.904	54 **Xe** 131.30
55 **Cs** 132.905	56 **Ba** 137.33	57-71 **La**	72 **Hf** 178.49	73 **Ta** 180.948	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.05	79 **Au** 196.966	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** [208.98]	85 **At** [209.99]	86 **Rn** [222.02]
87 **Fr** [223.02]	88 **Ra** [226.03]	89-103 **Ac**	104 **Rf** [265.12]	105 **Db** [268.13]	106 **Sg** [271.13]	107 **Bh** [270]	108 **Hs** [277.15]	109 **Mt** [276.15]	110 **Ds** [281.16]	111 **Rg** [280.16]	112 **Cn** [285.17]	113 **Nh** [284.18]	114 **Fl** [289.19]	115 **Mc** [288.19]	116 **Lv** [293]	117 **Ts** [294]	118 **Og** [294]

	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Lanthanides	**La** 138.905	**Ce** 140.12	**Pr** 140.907	**Nd** 144.24	**Pm** [145]	**Sm** 150.4	**Eu** 151.96	**Gd** 157.25	**Tb** 158.925	**Dy** 162.50	**Ho** 164.930	**Er** 167.26	**Tm** 168.934	**Yb** 173.04	**Lu** 174.967
	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Actinides	**Ac** [277.03]	**Th** 232.038	**Pa** 231.035	**U** 238.029	**Np** [237.05]	**Pu** [244.06]	**Am** [243.06]	**Cm** [247.07]	**Bk** [247.07]	**Cf** [251.08]	**Es** [252.08]	**Fm** [257.10]	**Md** [258.10]	**No** [259.10]	**Lr** [262.11]

$q = m \cdot c_s \cdot \Delta T$

$\Delta T_b = i \cdot K_b \cdot m$

$\mathrm{P_{solvent}} = \mathrm{X_{solvent}} \cdot \mathrm{P^o_{solvent}}$

$\ln\left(\frac{[A]_t}{[A]_0}\right) = -kt$

$[A]_t - [A]_0 = -kt$

$\mathrm{pH} = -\log[\mathrm{H_3O^+}]$

$\mathrm{pH} = \mathrm{pK}_a + \log\left(\frac{[A^-]}{[HA]}\right)$

$\Delta G^0 = \Delta H^0 - T\Delta S^0$

$\Delta E = B\left(\frac{1}{n_f^2 - n_i^2}\right)$

$\Delta G^0 = -nF\varepsilon^0$

$\Pi = MRT$

$F = 96485\ \frac{\mathrm{C}}{\mathrm{mol}}$

$R = 0.08206\ \frac{\mathrm{L \cdot atm}}{\mathrm{mol \cdot K}}$

$1.0\ \mathrm{kg} = 2.2\ \mathrm{lb}$

$1.0\ \mathrm{in} = 2.54\ \mathrm{cm}$

$1\ \mathrm{lb} = 453.59\ \mathrm{g}$

$c = 2.998 \times 10^8\ \mathrm{m/s}$

$h = 6.626 \times 10^{-34}\ \mathrm{J \cdot s}$

$\Delta T_f = i \cdot K_f \cdot m$

$S_{gas} = k_H \cdot P_{gas}$

$k = Ae^{-E_a/RT}$

$\frac{1}{[A]_t} - \frac{1}{[A]_0} = kt$

$\ln\left(\frac{k_2}{k_1}\right) = \frac{-E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$

$\ln\left(\frac{P_2}{P_1}\right) = \frac{-\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$

$\mathrm{pOH} = -\log[\mathrm{OH^-}]$

$\Delta S_{surr} = \frac{-\Delta H_{sys}}{T}$

$E_{cell}^\circ = E_{red}^\circ + E_{ox}^\circ$

$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$c = \lambda v$

$\Delta E = \boldsymbol{h}$

$K_w = 1.0 \times 10^{-14}$

$B = -2.18 \times 10^{-18}\ \mathrm{J}$

$N_A = 6.022 \times 10^{23}$

$1\ \mathrm{atm} = 101{,}325\ \mathrm{Pa} = 1.01325\ \mathrm{bar}$

$1\ \mathrm{J} = 1\ \mathrm{N \cdot m} = 1\ \mathrm{kg \cdot m \cdot s^2} = 0.239\ \mathrm{cal}$

$\lambda = \frac{\mathrm{h}}{\mathrm{m\ x\ v}}$

Assume all gases behave ideally unless specifically told to do otherwise

Assume all solutions are aqueous and at 25 °C unless specifically told otherwise
Assume all gases are at STP unless specifically told otherwise

Simple Rules for the Solubility of Salts in Water

1. Most nitrates are soluble
2. Most salts containing Group 1 ions or ammonium (NH_4^+) are soluble
3. Most chloride, bromide, and iodide salts are soluble except those of Ag^+, Pb^{2+}, and Hg_2^{2+}.
4. Most sulfates are soluble with the exception of Ba^{2+}, Pb^{2+}, Hg_2^{2+}, and Ca^{2+}
5. Most hydroxide salts are only slightly soluble with the exception of Group 1 hydroxides. Group 2 (Ba^{2+} to Ca^{2+}) are slightly soluble.
6. Most sulfides, carbonates, chromates, and phosphates are only slightly soluble

Academic Challenge
Chemistry Test (Sectional) – 2024

1. Which of the following has been named **incorrectly**?

   A. SF_6 sulfur hexafluoride
   B. FeS iron(I) sulfide
   C. PbO_2 lead(IV) oxide
   D. $(NH_4)_2SO_4$ ammonium sulfate
   E. $Ca(NO_3)_2$ calcium nitrate

2. How many of the following statements are **true**?

   I. All molecules are compounds.
   II. The terms “atom” and “element” always have the same meaning.
   III. Ions are formed by adding or removing electrons
   IV. Empirical formulas and molecular formulas are always different.

   A. 4
   B. 3
   C. 2
   D. 1
   E. 0

3. An excess of sugar is sitting at the bottom of a glass of sugar water. In order to increase the dissolution process of the sugar which of the following actions needs to be taken?

   A. Cool the glass.
   B. Add more sugar.
   C. Pour off some of the sugar solution.
   D. Add more water to the glass.
   E. Increase the pressure on the solution in the glass.

4. A compound consisting of carbon, hydrogen, and oxygen is found to contain 40.00% carbon by mass and 6.71% hydrogen by mass. Determine the empirical formula for this compound.

   A. C_2H_4O
   B. C_6HO_8
   C. $C_3H_7O_3$
   D. CH_2O
   E. none of these

5. The alkanes have a general formula:

   A. C_nH_{2n}
   B. C_nH_{2n+2}
   C. C_nH_{2n-2}
   D. C_nH_{2n+4}
   E. C_nH_{2n+6}

6. The atoms in a water molecule are held together by chemical bonds. Select the type of chemical bond that best describes those in water.

   A. ionic bond
   B. nonpolar covalent bond
   C. coordinate covalent bond
   D. hydrogen bond
   E. polar covalent bond

7. How many calories are necessary to raise the temperature of 48.2 g of cadmium from 55 ^{o}C to 75 ^{o}C? The molar heat capacity of Cd is 6.2 cal/(mol • ^{o}C).

   A. 53 cal
   B. 2.7 cal
   C. 960cal
   D. 5900 cal
   E. 230 cal

8. Which of the following species exhibits the strongest intermolecular forces?
   A. H_2O
   B. CH_4
   C. N_2
   D. CO
   E. He

9. What is the [OH^-] concentration and pH of a solution that is 1 x 10^{-4} *M* in hydrogen ion?

   A. pH = 4.0, [OH^-] = 1 x 10^{-4} *M*
   B. pH = 10.0, [OH^-] = 1 x 10^{-4} *M*
   C. pH = 10.0, [OH^-] = 1 x 10^{-10} *M*
   D. pH = 6.0, [OH^-] = 1 x 10^{-10} *M*
   E. pH = 4.0, [OH^-] = 1 x 10^{-10} *M*

10. According to the ideal gas law, at what temperature would a gas have no volume at all?

    A. 100 °C
    B. 0 °C
    C. 0 K
    D. 273 K
    E. –273 K

11. A piece of white paper would have sufficient density to stop the penetration of which of the following?

    A. alpha particle
    B. beta particle
    C. gamma radiation
    D. a high velocity electron
    E. a photon

12. The measurement of 0.5 mg is equal to which of the following?

    A. 0.05 dg
    B. 0.005 kg
    C. 5000 ng
    D. 500 µg
    E. 5 cg

13. The sum of protons and electrons for Na^+ and $C\ell^-$ are

    A. 28 protons, 28 electrons
    B. 27 protons, 28 electrons
    C. 58 protons, 58 electrons
    D. 28 protons, 30 electrons
    E. 11 protons, 11 electrons

14. Which of the following contains the greatest number of oxygen atoms?
    A. 100.0 g of CO_2
    B. 100.0 g of H_2O
    C. 1.00 mole of CO_2
    D. 2.00 moles of H_2O
    E. All of the above (A-D) contain the same number of oxygen atoms.

15. The K_{eq} for the equilibrium below is 7.52×10^{-2} at 480.0 ºC.

$$2\ C\ell_2(g) + 2\ H_2O(g) \rightleftharpoons 4\ HC\ell(g) + O_2(g)$$

    What is the value of K_{eq}, at this temperature, for the following reaction?

$$2\ HC\ell(g) + \tfrac{1}{2}\ O_2(g) \rightleftharpoons C\ell_2(g) + H_2O(g)$$

    A. –0.0376
    B. 0.274
    C. 3.65
    D. 13.3
    E. 5.66×10^{-3}

16. Consider the following reaction:

$$3\ A \rightarrow 2\ B$$

The average rate of appearance of B is given by Δ[B]/Δt. Comparing the rate of appearance of B and the rate of disappearance of A, we get Δ[B]/Δt = _____ x (Δ[A]/Δt).

A. –3/2
B. +3/2
C. +2/3
D. –2/3
E. +1

17. Which of the following has the largest second ionization energy?

A. Na
B. Mg
C. Aℓ
D. P
E. Si

18. Based on molecular orbital theory, the highest occupied molecular orbital in NO would be the _____.

A. σ_{2p}
B. σ_{2p}^{*}
C. π_{2p}^{*}
D. π_{2p}
E. σ_{2s}^{*}

19. How many grams of aluminum metal will be produced when an electric current of 12 amps is passed through molten AℓCℓ$_3$ for 2.5 hours? (1 amp = 1 C/s)

A. 30.2
B. 10.1
C. 90.7
D. 2.80 x 10^{-3}
E. 0.373

20. Calculate the longest wavelength of light (in nm) that can be used to remove electrons from metal surfaces if 245 kJ/mol is required to eject electrons.

    A. 165
    B. 725
    C. 552
    D. 233
    E. 489

21. Sulfur and fluorine react in a combination reaction to produce sulfur hexafluoride:

$$S(s) + 3\ F_2(g) \rightarrow SF_6(g)$$

    In an experiment, the percent yield is 83.1%. This means that in this experiment, a 4.50 g sample of fluorine yields _____ g of SF_6.

    A. 9.58
    B. 3.74
    C. 43.1
    D. 4.79
    E. 14.4

22. Consider the following reaction at equilibrium (in a sealed container):

$$2\ NH_3(g) \rightleftharpoons N_2(g) + 3\ H_2(g)$$

    Which of the following changes would result in an increase in the moles of H_2 in the reaction container?

    A. removal of NH_3 from the reaction vessel
    B. a decrease in total pressure
    C. an increase in total pressure by the addition of helium gas
    D. a decrease in the total volume of the reaction vessel
    E. addition of some N_2 to the reaction vessel

23. The solubility of Ar in water, at 25 ºC, is 1.6×10^{-3} *M* when the pressure of the Ar above the solution is 1.0 atm. Calculate the solubility of Ar at a pressure of 2.5 atm.

    A. 1.6×10^{3} *M*
    B. 7.5×10^{-2} *M*
    C. 6.4×10^{-4} *M*
    D. 1.6×10^{-3} *M*
    E. 4.0×10^{-3} *M*

24. A particular first-order reaction has a rate constant of $1.35 \times 10^{2}\ s^{-1}$ at 25.0 ºC. What is the magnitude of *k* at 65.0 ºC, if E_a = 55.5 kJ/mol?

    A. 1.95×10^{4}
    B. 1.35×10^{2}
    C. 1.91×10^{3}
    D. 358
    E. 3.48×10^{73}

25. How many different principal quantum numbers can be found in the ground-state electron configuration of nickel?

    A. 4
    B. 3
    C. 2
    D. 6
    E. 5

26. A 934 g object is traveling at a velocity of 35.0 m/s. What is the de Broglie wavelength of this object?

    A. 2.03×10^{-32} m
    B. 2.03×10^{-38} m
    C. 2.03×10^{36} m
    D. 2.03×10^{33} m
    E. 2.03×10^{-35} m

27. The ground-state electron configuration of the element _____ is $[Kr]5s^{1}4d^{5}$.

    A. Nb
    B. Mo
    C. Cr
    D. Mn
    E. Tc

28. Element M reacts with chlorine to form a compound with the formula $MC\ell_2$. Element M is more reactive than magnesium and has a smaller radius than barium. Identify element M.

    A. Be
    B. Na
    C. Sr
    D. Ra
    E. K

29. A titration reached the equivalence point when 16.1 mL of 0.209 *M* H_2SO_4(aq) was added to 12.0 mL of NaOH(aq) of unknown concentration. What is the concentration of this unknown NaOH solution?

    A. 0.140 *M*
    B. 80.8 *M*
    C. 0.280 *M*
    D. 0.561 *M*
    E. 3.21 *M*

30. What is the vapor pressure lowering, in mmHg, of water at 25 ºC when a solution is prepared by dissolving 20.5 g of $CO(NH_2)_2$ in 75.0 g of water? The vapor pressure of pure water at 25 ºC is 23.8 mmHg.

    A. 27
    B. 22
    C. 0.91
    D. 0.42
    E. 1.8

31. Which of the following statements is true?

    A. The principal quantum number (n) describes the shape of an orbital.
    B. An orbital is the path that an electron follows during its movement in an atom.
    C. The angular momentum quantum number (ℓ) describes the size and energy associated with an orbital.
    D. The magnetic quantum number (m_ℓ) describes the orientation of the orbital.
    E. All of the above are true

32. A solution at 20 ºC that is 3.75 *m* in $MnSO_4$ monohydrate is considered a(n) _____ solution. The solubility of $MnSO_4$ monohydrate in water at 20 ºC is 70.0 g per 100.0 mL of water.

    A. unsaturated
    B. supersaturated
    C. solvated
    D. saturated
    E. hydrated

33. What is the oxidation number of sulfur in ZnS_2O_3?

    A. 0
    B. +2
    C. –2
    D. +1
    E. –1

34. A solution is prepared by dissolving 0.23 mol of hypochlorous acid (HCℓO, $K_a = 1.36 \times 10^{-3}$) and 0.27 mol of sodium hypochlorite (NaCℓO) in water sufficient to yield 1.00 L of solution. The addition of 0.05 mol of HCℓ to this solution causes the pH to drop slightly. Why does the pH does not decrease drastically?

    A. The HCℓ reacts with the hypochlorite ion in solution.
    B. The HCℓ ionizes into H_3O^+ which only slightly lowers the pH.
    C. The HCℓ reacts with hydroxide in the solution to produce water.
    D. The HCℓ reacts with the hypochlorous acid in solution.
    E. This is a buffer solution: the pH does not change upon addition of acid or base.

35. Which formula/name is **incorrect**?

    A. $PC\ell_5$ Phosphorus pentachloride
    B. $Fe(OH)_2$ Iron(II) hydroxide
    C. $(NH_4)_2CO_3$ Ammonium carbonate
    D. $BaC\ell_2$ Barium chloride
    E. K_2S Dipotassium sulfide

36. Consider the reaction at constant pressure.

    $C_2H_5OH(\ell) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(\ell)$ $\Delta H = -1.37 \times 10^3$ kJ

    When a 23.0 gram sample of C_2H_5OH is reacted with enough oxygen, how much energy is released as heat?

    A. 137 kJ
    B. 3.15×10^4 kJ
    C. 6.85×10^2 kJ
    D. 1.37×10^3 kJ
    E. 59.6 kJ

37. You measure the length of a table as 3.1400 meters. How many significant figures are in the measurement?

    A . 1
    B . 2
    C . 3
    D . 4
    E. 5

38. The total number of lone-pairs in $PC\ell_3$ is:

    A. 6
    B. 10
    C. 9
    D. 8
    E. 1

39. The difference in the strength of the intermolecular forces between methane (CH_4) and ammonia (NH_3) is mainly due to

    A. the fact that methane is polar and ammonia is nonpolar.
    B. methane (with four hydrogens) has a greater chance to exhibit hydrogen bonding than ammonia (with three hydrogens).
    C. the fact that ammonia is polar and methane is nonpolar.
    D. the different molar masses.
    E. There is no difference in the strength of the intermolecular forces between methane and ammonia.

40. Which of the following is an example of a basic anhydride?

    A. LiOH
    B. H_2SO_3
    C. BaO
    D. CO_2
    E. $C\ell_2O_3$

SCRATCH PAPER