



# 2024 Academic Challenge

## CHEMISTRY TEST – REGIONAL

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

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

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

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

$$P_{\text{solvent}} = X_{\text{solvent}} \cdot P_{\text{solvent}}^{\circ}$$

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

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

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

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

$$\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ}$$

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

$$\Delta G^{\circ} = -nF\epsilon^{\circ}$$

$$\Pi = MRT$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$c = \lambda v$$

$$\Delta E = h$$

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

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

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

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

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

$$\lambda = \frac{h}{m \times v}$$

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 ( $\text{NH}_4^+$ ) are soluble
3. Most chloride, bromide, and iodide salts are soluble except those of  $\text{Ag}^+$ ,  $\text{Pb}^{2+}$ , and  $\text{Hg}_2^{2+}$ .
4. Most sulfates are soluble with the exception of  $\text{Ba}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Hg}_2^{2+}$ , and  $\text{Ca}^{2+}$
5. Most hydroxide salts are only slightly soluble with the exception of Group 1 hydroxides. Group 2 ( $\text{Ba}^{2+}$  to  $\text{Ca}^{2+}$ ) are slightly soluble.
6. Most sulfides, carbonates, chromates, and phosphates are only slightly soluble

Academic Challenge  
Chemistry Test (Regional) – 2024

- Which of the following has the greatest number of significant figures?
  - $1.20 \times 10^3$
  - 1200
  - $0.00012 \times 10^7$
  - $12 \times 10^2$
  - $0.012 \times 10^5$
- Which of the following is an isotope of the carbon-12 atom?
  - An atom with 12 protons and 14 neutrons.
  - An atom with 8 protons and 6 neutrons.
  - An atom with 6 protons and 6 neutrons.
  - An atom with 8 protons and 8 neutrons.
  - An atom with 6 protons and 8 neutrons.
- Water has a density of 1.0 g/mL. Which of the objects will float in water?
  - Object I: mass = 50.0 g; volume = 60.8 mL
  - Object II: mass = 65.2 g; volume = 42.1 mL
  - Object III: mass = 100.0 g; volume = 20.0 mL
  - I
  - I, III
  - II
  - II, III
  - III
- How many moles of hydrogen atoms are present in 25.0 g of water?
  - 1.00
  - 1.39
  - 2.00
  - 2.78
  - $6.022 \times 10^{23}$
- Which of the following names is incorrect?
  - cobalt(II) chloride
  - magnesium oxide
  - aluminum(III) oxide
  - diphosphorus pentoxide
  - all of the above names are incorrect.

6. The approximate bond angle value in  $\text{NH}_3$  is
- A.  $90^\circ$
  - B.  $109.5^\circ$
  - C.  $120^\circ$
  - D.  $180^\circ$
  - E.  $60^\circ$
7. In lab one day, you measure 4.21 g of a substance. Your lab partner measures 97.46 g of the same substance. You put your samples together in one beaker and record the mass. How many significant figures should you report?
- A. 1
  - B. 2
  - C. 3
  - D. 4
  - E. 5
8. How many protons and electrons does the most stable ion of oxygen in a compound have?

	<u># protons</u>	<u>#electrons</u>
A.	10	8
B.	8	6
C.	6	8
D.	8	8
E.	8	10

9. Which of the following is **not** a chemical change?
- A. The digestion of food.
  - B. Mixing aqueous solutions of lead(II) nitrate and potassium chloride.
  - C. The burning of firewood.
  - D. Mixing aqueous solutions of potassium nitrate and sodium chloride.
  - E. All of the above are examples of chemical changes.
10. Which compound has the greatest molar mass?
- A. iron(III) oxide
  - B. iron(II) oxide
  - C. iron(II) hydroxide
  - D. iron(III) hydroxide
  - E. iron(II) sulfate

11. Which one of the following species is nonpolar?
- A.  $\text{CCl}_4$
  - B.  $\text{CHCl}_3$
  - C.  $\text{CH}_2\text{Cl}_2$
  - D.  $\text{CH}_3\text{Cl}$
  - E. None of the above
12. According to the significant figure rules how many significant figures can there be in the final answer for the following problem?  $(85.3 - 21.489) \div 0.0059$ .
- A. 1
  - B. 2
  - C. 3
  - D. 4
  - E. 5
13. The molar mass of iron(II) oxide (units of g/mol) is
- A. 87.8
  - B. 127.7
  - C. 71.8
  - D. 159.7
  - E. none of these
14. What is the general name given to hydrocarbons with triple bonds?
- A. saturated hydrocarbons
  - B. aromatic hydrocarbons
  - C. alkynes
  - D. alkanes
  - E. alkenes
15. A solution of sodium fluoride is added dropwise to a solution that is  $0.0122\text{ M}$  in barium ions. When the concentration of fluoride exceeds \_\_\_\_\_  $\text{M}$ , a precipitate will form. Useful information:  $K_{\text{sp}} = 1.7 \times 10^{-6}$ .
- A.  $3.0 \times 10^{-3}$
  - B.  $1.2 \times 10^{-2}$
  - C.  $2.1 \times 10^{-8}$
  - D.  $7.0 \times 10^{-5}$
  - E.  $1.4 \times 10^{-4}$
16. Which one of the following substances would be the most soluble in carbon tetrachloride?
- A.  $\text{NH}_3$
  - B.  $\text{Li}_2\text{O}$
  - C.  $\text{C}_4\text{H}_{10}$
  - D.  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$
  - E.  $\text{HCl}$

17. The standard cell potential of the reaction below is +1.34 V. The value of  $\Delta G^\circ$  for the reaction is \_\_\_\_\_ kJ.



- A. -259
- B. -24.3
- C. +776
- D. -776
- E. +259

18. Visible light with a wavelength of 550 nm has a frequency of \_\_\_\_\_ MHz.

- A. 0.55
- B.  $1.7 \times 10^5$
- C.  $5.5 \times 10^{11}$
- D.  $5.5 \times 10^8$
- E.  $5.5 \times 10^{20}$

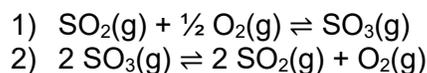
19. Screening of the nuclear charge by core electrons in atoms is \_\_\_\_\_.

- A. less efficient than that by valence electrons
- B. essentially identical to that by valence electrons
- C. more efficient than that by valence electrons
- D. responsible for a general decrease in atomic radius going down a group
- E. both essentially identical to that by valence electrons and responsible for a general decrease in atomic radius going down a group

20. Which one of the following represents an impossible set of quantum numbers for an electron in an atom (arranged as  $n$ ,  $l$ ,  $m_l$ , and  $m_s$ )?

- A. 4, 3, 0, 0
- B. 4, 3, -3,  $+\frac{1}{2}$
- C. 4, 3, 0,  $+\frac{1}{2}$
- D. 4, 2, -2,  $-\frac{1}{2}$
- E. 4, 3, 3,  $-\frac{1}{2}$

21. The equilibrium constant for reaction 1 is  $K$ . What is the equilibrium constant for reaction 2?



- A.  $\frac{1}{2} K$
- B.  $1/K^2$
- C.  $2 K$
- D.  $-K^2$
- E.  $K^2$

22.  $\text{GeF}_3\text{H}$  is formed from  $\text{GeH}_4$  and  $\text{GeF}_4$  in the combination reaction below. If the reaction yield is 89.1 %, how many moles of  $\text{GeF}_4$  are needed to produce 3.50 moles of  $\text{GeF}_3\text{H}$ ?



- A. 0.875  
 B. 2.95  
 C. 0.982  
 D. 15.7  
 E. 3.93
23. A solution is prepared by dissolving 27.7 g of  $\text{CaCl}_2$  in 375 g of water. The density of the resulting solution is 1.05 g/mL. Calculate the percent, by mass, of  $\text{CaCl}_2$ .

- A. 6.88  
 B. 6.24  
 C. 7.22  
 D. 0.0722  
 E. 0.0688

24. Which electron configuration represents a violation of the Pauli exclusion principle?

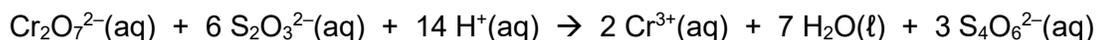
- A.  $\begin{array}{c} \uparrow\downarrow \\ 1s \end{array} \begin{array}{c} \uparrow \\ 2s \end{array} \begin{array}{c} \text{---} \\ 2p \end{array}$
- B.  $\begin{array}{c} \uparrow\downarrow \\ 1s \end{array} \begin{array}{c} \uparrow\downarrow \\ 2s \end{array} \begin{array}{c} \uparrow\downarrow \\ 2p \end{array} \text{---}$
- C.  $\begin{array}{c} \uparrow\downarrow \\ 1s \end{array} \begin{array}{c} \uparrow\downarrow \\ 2s \end{array} \begin{array}{c} \uparrow \text{---} \uparrow \\ 2p \end{array}$
- D.  $\begin{array}{c} \uparrow \\ 1s \end{array} \begin{array}{c} \uparrow \\ 2s \end{array} \begin{array}{c} \uparrow \uparrow \uparrow \\ 2p \end{array}$
- E.  $\begin{array}{c} \uparrow\downarrow \\ 1s \end{array} \begin{array}{c} \uparrow\uparrow \\ 2s \end{array} \begin{array}{c} \uparrow \text{---} \text{---} \\ 2p \end{array}$

25. In a  $p_x$  orbital, the subscript x denotes the \_\_\_\_\_.

- A. axis along which the orbital is aligned  
 B. energy of the electron  
 C. probability of the shell  
 D. size of the orbital  
 E. spin of the electrons

26. The atomic radius of main-group elements generally increases down a group because \_\_\_\_.
- A. the effective nuclear charge decreases down a group
  - B. the effective nuclear charge increases down a group
  - C. the effective nuclear charge zigzags down a group
  - D. the principal quantum number of the valence orbitals increases
  - E. both the effective nuclear charge increases down a group and the principal quantum number of the valence orbitals increases
27. What is the coefficient on  $O_2$  when  $C_4H_8O_2$  undergoes a combustion reaction?
- A. 3
  - B. 6
  - C. 2
  - D. 1
  - E. 5
28. A sample of carbon dioxide contains 3.549 moles of atoms. What is the mass of the sample?
- A.  $2.137 \times 10^{24}$  g
  - B. 52.06 g
  - C. 156.2 g
  - D. 0.2419 g
  - E.  $7.124 \times 10^{23}$  g
29. Which of the following will have the greatest effect on the freezing point of water if one mole is used to make an aqueous solution?
- A.  $NH_4NO_3$
  - B. sucrose
  - C.  $Li_2CO_3$
  - D. NaF
  - E.  $Li_3PO_4$
30. Which statement below would be true when comparing an electronic transition from  $n = 2$  to  $n = 3$  with a transition from  $n = 3$  to  $n = 4$ ?
- A. The lower energy transition would be  $n = 2$  to  $n = 3$ .
  - B. Both transitions would have the same energy.
  - C. The higher wavelength transition would be  $n = 2$  to  $n = 3$ .
  - D. The lower frequency transition would be  $n = 3$  to  $n = 4$ .
  - E. Both transitions would release energy in the form of light.

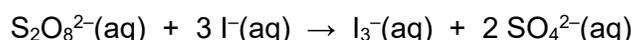
31. Which element is reduced in the following reaction?



- A.  $\text{S}_4\text{O}_6^{2-}$
- B. H
- C. Cr
- D. S
- E. O

32. The peroxydisulfate ion reacts with the iodide ion in aqueous solution via the reaction below. An aqueous solution containing  $0.050 \text{ M}$  of  $\text{S}_2\text{O}_8^{2-}$  ion and  $0.072 \text{ M}$   $\text{I}^-$  is prepared, and the progress of the reaction is followed by measuring  $[\text{I}^-]$ . The data is shown in the table. Calculate the concentration of  $\text{S}_2\text{O}_8^{2-}$  remaining at 1200 s.

Time (s)	0.000	400.0	800.0	1200.0	1600.0
$[\text{I}^-]$ (M)	0.072	0.057	0.046	0.037	0.029



- A.  $0.035 \text{ M}$
- B.  $0.012 \text{ M}$
- C.  $-0.012 \text{ M}$
- D.  $-0.038 \text{ M}$
- E.  $0.038 \text{ M}$

33. In an exothermic reaction

- A. heat is required.
- B. heat is considered a reactant.
- C. the reactants are more stable than the products.
- D. the products are more stable than the reactants.
- E. None of the above.

34. What type(s) of intermolecular forces is/are exhibited by methane ( $\text{CH}_4$ )?

- A. hydrogen bonding and London dispersion forces
- B. hydrogen bonding
- C. London dispersion forces
- D. dipole-dipole and London dispersion forces
- E. ionic bonding

35. Calculate the pH of 100.0 mL of  $0.0200 \text{ M}$  NaOH.

- A. 1.70
- B. 2.70
- C. 11.30
- D. 12.30
- E. None of the above

36. Determine the pressure exerted by 1.80 mol of a gas in a 2.92 L container at 32.0 °C. (Assume ideal behavior.)
- A. 8.57 atm
  - B. 15.4 atm
  - C. 22.4 atm
  - D. 1.62 atm
  - E. 495 atm
37. Nuclear magnetic resonance spectroscopy (NMR) is the most valuable spectroscopic technique available to organic chemists. NMR is more commonly known for its use in:
- A. irradiating cancer through the use of proton therapy
  - B. MRI as a diagnostic method of viewing inside the human body
  - C. grocery store scanners
  - D. LASIK for corrective laser eye surgery
  - E. HI-Definition television
38. The specific heat of water is  $4.184 \text{ J} \cdot \text{g}^{-1} \cdot ^\circ\text{C}^{-1}$ , and that of copper is  $0.382 \text{ J} \cdot \text{g}^{-1} \cdot ^\circ\text{C}^{-1}$ . Water \_\_\_\_\_ heat compared to copper when equal masses of water and copper both initially at 75 °C cool down to 25 °C.
- A. releases less
  - B. absorbs less
  - C. releases more
  - D. absorbs more
  - E. absorbs and releases the same amount
39. Which one of the following will act as an acid in water solution?
- A.  $\text{CO}_2$
  - B.  $\text{NH}_3$
  - C.  $\text{CaCO}_3$
  - D.  $\text{Na}_2\text{CO}_3$
  - E.  $\text{NaHCO}_3$
40. A 248-mL gas sample has a mass of 0.433 g at a pressure of 745 mmHg and a temperature of 28 °C. What is the molar mass of the gas?
- A. 84.2 g/mol
  - B. 55.2 g/mol
  - C. 22.4 g/mol
  - D. 17.2 g/mol
  - E. 44.0 g/mol

# Scratch Paper