



2024 Academic Challenge

CHEMISTRY TEST – STATE

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 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 VIII B	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
Actinides	89 Ac [277.03]	90 Th 232.038	91 Pa 231.035	92 U 238.029	93 Np [237.05]	94 Pu [244.06]	95 Am [243.06]	96 Cm [247.07]	97 Bk [247.07]	98 Cf [251.08]	99 Es [252.08]	100 Fm [257.10]	101 Md [258.10]	102 No [259.10]	103 Lr [262.11]

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

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

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

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

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

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

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

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

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

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

$$\Pi = MRT$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$c = \lambda \nu$$

$$\Delta E = h$$

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

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

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

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

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

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

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 (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

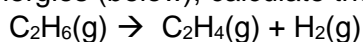
Academic Challenge
Chemistry Test (State) – 2024

1. A student performs an experiment to determine the density of a sugar solution. She obtains the following results: 1.71 g/mL, 1.73 g/mL, 1.67 g/mL, 1.69 g/mL. If the actual value for the density of the sugar solution is 1.40 g/mL, which statement below best describes her results?
 - A. Her results are accurate, but not precise.
 - B. Her results are neither precise nor accurate.
 - C. Her results are precise, but not accurate.
 - D. Her results are both precise and accurate.
 - E. None of the above are valid answer.
2. Select the statement that is **not** correct concerning the nature of an atom.
 - A. The identity of the atom lies in the nucleus with the number of protons.
 - B. The mass of the atom lies in the nucleus.
 - C. Electrons have a negligible amount of mass.
 - D. The number of electrons outside the nucleus is equal to the number of protons and neutrons within the nucleus.
 - E. Protons and neutrons are not exclusively equal in number to each other.
3. Which property is **not** a physical property of matter?
 - A. density
 - B. freezing point
 - C. combustibility
 - D. boiling point
 - E. conductivity
4. Which of the four following five samples contain the most atoms?
 - A. 50 g of potassium
 - B. 50 g of oxygen gas
 - C. 50 g of sodium
 - D. 50 g of magnesium
 - E. 50 g of chlorine gas
5. The electron dot formula for the polyatomic ion CN^- shows:
 - A. a single covalent bond
 - B. a triple covalent bond
 - C. a double covalent bond
 - D. an ionic bond
 - E. 13 electrons dots

6. Which functional group is **NOT** present in this molecule in the right most cell?

A.	ketone	
B.	carboxylic acid	
C.	amine	
D.	alcohol	
E.	alkene	

7. Given the bond energies (below), calculate the ΔH_{rxn} for the chemical reaction below.



<u>Bond Type</u>	<u>Average Bond Energy (kJ/mol)</u>
C-H	410
C-C	350
C=C	617
H-H	429

- A. 0 kJ
 B. 124 kJ
 C. -696 kJ
 D. 60 kJ
 E. 188 kJ
8. Which of the following decreases as the strength of intermolecular forces increases?
- A. boiling point
 B. melting point
 C. vapor pressure
 D. surface tension
 E. All of the above increase as the strength of intermolecular forces increases.
9. A certain isotope X^+ contains 54 electrons and 78 neutrons. What is the mass number for this element?
- A. 133
 B. 132
 C. 131
 D. 55
 E. 53

10. How many of the following describe a neutral solution?

- I. pH = 7.00 regardless of the temperature of the solution.
- II. Amount of base = amount of acid in any titration
- III. $[H^+] = [OH^-]$ regardless of the temperature of the solution
- IV. Any salt is dissolved in water at 25 °C.

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

11. Three 1.0 L containers each hold a different gas at STP. Which statement is correct about the number of molecules in each container?

<u>Container X</u>	<u>Container Y</u>	<u>Container Z</u>
F ₂	NO ₂	H ₂

- A. Container X has the greatest number of molecules.
- B. Container Y has the greatest number of molecules.
- C. Container Z has the greatest number of molecules.
- D. All three containers have the same number of molecules.
- E. There is not enough information to determine the number in each.

12. How many cm³ are contained in 2.67 x 10⁴ mm³?

- A. 2.67 x 10⁶ cm³
- B. 2.67 x 10⁴ cm³
- C. 2.67 x 10¹ cm³
- D. 2.67 x 10⁻¹⁰ cm³
- E. 2.67 x 10⁻⁶ cm³

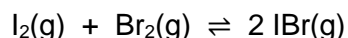
13. Which of the following atoms has two **more** electrons than protons as a stable ion in an ionic compound?

- A. S
- B. Ar
- C. Na
- D. Ca
- E. Cl

14. Which of the following describes an endothermic reaction?

- A. A reaction that causes the temperature of the surroundings to rise.
- B. A reaction in which the change in enthalpy is less than zero.
- C. A reaction that absorbs heat from the surroundings into the system.
- D. A reaction that transfers heat from the system into the surroundings.
- E. None of the above is correct.

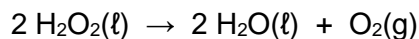
15. A sealed 1.0 L flask is charged with 0.500 mol of I_2 and 0.500 mol Br_2 . The equilibrium below ensues:



What is the value of K_{eq} if the flask contains 0.84 mol of IBr at equilibrium?

- A. 110
- B. 4
- C. 11
- D. 6.1
- E. 2.8

16. A plot of $\ln[H_2O_2]$ vs time for the reaction below yields a straight line.



A solution originally at 0.600 M H_2O_2 is found to be 0.075 M after 54 min. Calculate the half-life for this reaction.

- A. 14 min
- B. 6.8 min
- C. 28 min
- D. 54 min
- E. 18 min

17. A solution is prepared by dissolving 23.7 g of $CaCl_2$ in 375 g of water. The density of the resulting solution is 1.05 g/mL. What is the concentration of Cl^- in this solution?

- A. 0.562 M
- B. 6.64×10^{-2} M
- C. 0.214 M
- D. 1.20 M
- E. 1.12 M

18. Determine the molar solubility of BaF_2 in a solution containing 0.0750 M LiF . The K_{sp} for BaF_2 is 1.7×10^{-6} .

- A. $2.3 \times 10^{-5}\text{ M}$
- B. $8.5 \times 10^{-7}\text{ M}$
- C. $3.0 \times 10^{-4}\text{ M}$
- D. $1.2 \times 10^{-2}\text{ M}$
- E. 0.0750 M

19. Electromagnetic radiation with a wavelength of 641 nm appears as orange light to the human eye. The energy of one photon of this light is $3.10 \times 10^{-19}\text{ J}$. How many photons are emitted by a laser that emits $1.3 \times 10^{-2}\text{ J}$ of energy in a pulse of this orange light?

- A. 6.3×10^{-24}
- B. 6.5×10^{13}
- C. 4.2×10^{16}
- D. 2.4×10^{-17}
- E. 2.7×10^{19}

20. The data in the table below were obtained for the reaction: $\text{A} + \text{B} \rightarrow \text{C}$.

Experiment Number	[A], <i>M</i>	[B], <i>M</i>	Initial Rate (<i>M/s</i>)
1	0.451	0.885	1.13
2	0.451	1.77	1.13
3	1.35	0.885	10.17

What is the overall order of the reaction?

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

21. The principal reason for the extremely low solubility of NaCl in benzene (C_6H_6) is the _____.

- A. strength of the covalent bond in NaCl
- B. weak solvation of Na^+ and Cl^- by C_6H_6
- C. increased disorder due to mixing of solute and solvent
- D. strong solvent-solvent interactions
- E. hydrogen bonding in C_6H_6

22. Consider the following data:

Half-reaction	E° (V)
$\text{Cr}^{3+}(\text{aq}) + 3\text{e}^- \rightarrow \text{Cr}(\text{s})$	-0.74
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Fe}(\text{s})$	-0.440
$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightarrow \text{Fe}^{2+}(\text{aq})$	+0.771
$\text{Sn}^{4+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Sn}^{2+}(\text{aq})$	+0.154

Which of the following reactions will occur spontaneously?

- A. $3 \text{Fe}(\text{s}) + 2 \text{Cr}^{3+}(\text{aq}) \rightarrow 2 \text{Cr}(\text{s}) + 3 \text{Fe}^{2+}(\text{aq})$
 B. $\text{Sn}^{4+}(\text{aq}) + 2 \text{Fe}^{2+}(\text{aq}) \rightarrow \text{Sn}^{2+}(\text{aq}) + 2 \text{Fe}^{3+}(\text{aq})$
 C. $3 \text{Fe}^{2+}(\text{aq}) \rightarrow \text{Fe}(\text{s}) + 2 \text{Fe}^{3+}(\text{aq})$
 D. $3 \text{Sn}^{4+}(\text{aq}) + 2 \text{Cr}(\text{s}) \rightarrow 2 \text{Cr}^{3+}(\text{aq}) + 3 \text{Sn}^{2+}(\text{aq})$
 E. $\text{Sn}^{2+}(\text{aq}) + \text{Fe}^{2+}(\text{aq}) \rightarrow \text{Sn}^{4+}(\text{aq}) + \text{Fe}(\text{s})$
23. Atomic sulfur and molecular oxygen react to produce sulfur trioxide, an environmental pollutant. If 1.00 g of both reactants is used in the reaction, how much of the excess reagent will be left over when the reaction is complete?
- A. 0.00 g
 B. 0.320 g
 C. 0.669 g
 D. 0.332 g
 E. 0.849 g
24. Element X reacts with oxygen to form an oxide with the formula XO_2 . When XO_2 is dissolved in water, the resulting solution is acidic. Element X could be ____.
- A. oxygen
 B. aluminum
 C. lead(IV)
 D. calcium
 E. carbon
25. Calculate the wavelength of light emitted when an electron in a hydrogen atom moves from the 5s sublevel to the 2p sublevel.
- A. 410 nm
 B. 434 nm
 C. 93.8 nm
 D. 657 nm
 E. 487 nm

26. A 2.05 *m* aqueous solution of some unknown compound had a boiling point of 102.1 °C. Which one of the following could be the unknown compound? The boiling point elevation constant for water is 0.51 °C/*m*.
- A. C₆H₁₂O₆
 - B. CaBr₂
 - C. CH₃OH
 - D. Na₂CO₃
 - E. NaCl
27. The photoelectric effect is _____.
- A. a relativistic effect
 - B. the ejection of electrons by a metal when struck with light of sufficient energy
 - C. the darkening of photographic film when exposed to an electric field
 - D. the total reflection of light by metals giving them their typical luster
 - E. the production of current by silicon solar cells when exposed to sunlight
28. At 200 °C, the equilibrium constant (K_p) for the conversion of NO to oxygen gas and nitrogen gas is 2.40×10^3 . A closed vessel is charged with 36.1 atm of NO. What is the partial pressure of O₂, in atm, at equilibrium?
- A. 294
 - B. 6.00
 - C. 17.9
 - D. 35.7
 - E. 1.50×10^{-2}
29. Which of the following could not occur as the wavelength of a photon increases?
- A. observed color becomes more violet
 - B. energy decreases
 - C. frequency decreases
 - D. amplitude remains unchanged
 - E. none of the above
30. Choose the electron configuration of the atom with the most negative electron affinity.
- A. 1s²2s²2p⁶3s¹
 - B. 1s²2s²2p⁶3s²
 - C. 1s²2s²2p⁶3s²3p¹
 - D. 1s²2s²2p⁶3s²3p⁶
 - E. 1s²2s²2p⁶3s²3p⁵

31. Which orbital is degenerate with a $3d_{z^2}$?
- A. $3d_{zz}$
 - B. $5d_{z^2}$
 - C. $4d_{z^2}$
 - D. $3d_{yz}$
 - E. $4d_{xz}$
32. Which of the following pairs cannot be mixed together to form a buffer solution?
- A. HONH_2 , HONH_3Cl
 - B. KOH , HNO_2
 - C. H_2SO_3 , KHSO_3
 - D. NaCl , HCl
 - E. RbOH , HF
33. Which of the following would not be considered a colligative property of solutions?
- A. the increase of the melting point of a solution upon the addition of a solute to a solvent
 - B. elevation of the boiling point of a solution upon the addition of a solute to a solvent
 - C. an increase in the osmotic pressure of a solution upon the addition of more solute
 - D. depression of the freezing point of a solution upon the addition of a solute to a solvent
 - E. depression of the vapor pressure upon the addition of a solute to a solvent
34. What is the correct ground state electron configuration for chromium(III)?
- A. $[\text{Ar}]4d^3$
 - B. $[\text{Ar}]4s^23d^1$
 - C. $[\text{Ar}]4s^13d^2$
 - D. $[\text{Kr}]4s^14d^2$
 - E. $[\text{Ar}]3d^3$
35. A compound containing carbon, hydrogen, and oxygen is 68.84% carbon by mass and 4.95% hydrogen by mass. What is its empirical formula?
- A. C_{14}H
 - B. C_{14}HO_5
 - C. $\text{C}_5\text{H}_5\text{O}_2$
 - D. $\text{C}_{10}\text{H}_{10}\text{O}_3$
 - E. $\text{C}_7\text{H}_6\text{O}_2$

36. The chemical name of $\text{Ga}(\text{BrO}_4)_3$ is:

- A. Gallium(III) bromate
- B. Gallium(III) bromite
- C. Gallium(III) hypobromite
- D. Gallium(III) perbromate
- E. Gallium(III) perbromite

37. Which of the following is likely to be a solid at room temperature?

- A. Na_2S
- B. HF
- C. NH_3
- D. N_2
- E. H_2O

38. A 4.37 gram sample of a certain diatomic gas occupies a volume of 3.00-L at 1.00 atm and a temperature of 45°C . Identify this gas.

- A. F_2
- B. N_2
- C. H_2
- D. O_2
- E. Cl_2

39. Which of the following pH solution is 10 times more acidic than a solution with $\text{pH} = 5$?

- A. $\text{pH} = 50$
- B. $\text{pH} = 0.5$
- C. $\text{pH} = 6$
- D. $\text{pH} = 4$
- E. $\text{pH} = 4.5$

40. The conjugate base of sulfuric acid is:

- A. H_2SO_3
- B. HSO_4^{2-}
- C. SO_3^{2-}
- D. SO_4^{2-}
- E. HSO_4^-

SCRATCH PAPER

