

ACADEMIC CHALLENGE FOR
ACES
ENGINEERING AND SCIENCE



EASTERN ILLINOIS UNIVERSITY

2023 Academic Challenge

SECTIONAL CHEMISTRY EXAM

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!

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Periodic Table of the Elements

1 IA													13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA											
1 H 1.0079												5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.179												
2 IIA	3 Li 6.941	4 Be 9.012										11 Na 22.990	12 Mg 24.305	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.06	17 Cl 35.453	18 Ar 39.948										
		3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 ← VIII	9 VIII	10 →	11 IB	12 IIB	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 La 138.905	58 Ce 140.12	59 Pr 140.907	60 Nd 144.24	61 Pm [145]	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
	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]

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

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

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

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

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

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

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

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

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

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

$$\Pi = MRT$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$c = \lambda\nu$$

$$\Delta E = h\nu$$

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

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

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

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

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

Assume all gases behave ideally unless specifically told to do otherwise

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

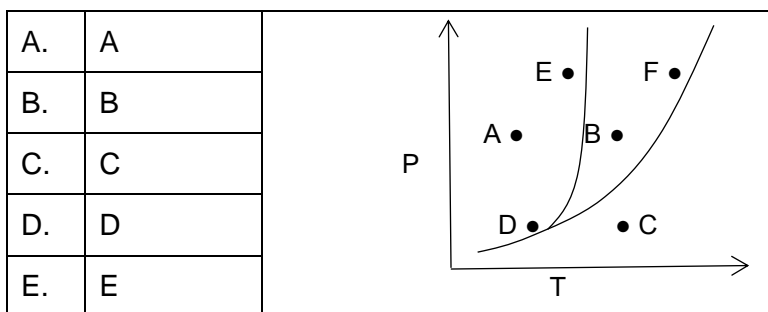
Assume all gases are at STP unless specifically told otherwise

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

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- All of the following statements are false EXCEPT
 - copper (Cu) is a homogeneous mixture of carbon (C) and uranium (U).
 - Table salt is a heterogeneous mixture of sodium metal and chlorine gas.
 - Soda water is a homogeneous mixture of carbon dioxide gas and water.
 - AgCl dissolves completely in water to give a homogeneous mixture.
 - Water (H₂O) is a homogeneous mixture containing hydrogen and oxygen.
- What is the correct formula of chromium(III) nitrite?
 - Cr(NO₂)₃
 - Cr₃NO₃
 - Cr₃NO₂
 - Cr₂(NO₂)₃
 - Cr(NO₃)₃
- According to the VSEPR theory which of the following is the molecular geometry of SO₂?
 - linear
 - bent
 - triangular planar
 - triangular pyramidal
 - tetrahedral
- Water has a specific heat capacity of 4.18 J/g·°C. If 35.0 g of water at 98.8 °C loses 4.98 kJ of heat, what is the final temperature of the water?
 - 32.0 °C
 - 46.2 °C
 - 47.5 °C
 - 57.2 °C
 - 65.0 °C
- On the phase diagram (right side of the table), which point corresponds to conditions where both the solid and liquid phases exist?



6. What is the conjugate base of HNO_2 ?
- A. H^+
 - B. H^-
 - C. NO_2^+
 - D. NO_2
 - E. NO_2^-
7. If the volume of a confined gas is doubled at constant temperature, what change is expected?
- A. The pressure of gas is decreased to $\frac{1}{4}$ of its original value.
 - B. The pressure of gas is decreased to $\frac{1}{2}$ of its original value.
 - C. The pressure of gas is increased to twice of its original value.
 - D. The density of gas is doubled.
 - E. The velocities of the molecules are doubled.
8. Gamma (γ) rays are
- A. helium nuclei with no mass.
 - B. electrons with no mass.
 - C. high energy radiations.
 - D. slow moving neutrons.
 - E. identical to electrons.
9. What are the values for x and y, respectively, in $\text{Ca}_x\text{H}_y\text{PO}_4$?
- A. 1 and 2
 - B. 2 and 1
 - C. 1 and 3
 - D. 2 and 2
 - E. 1 and 1
10. Which of the following reactions is likely to have the most positive change in entropy?
- A. $\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g}) \rightarrow 2 \text{NH}_3(\text{g})$
 - B. $\text{N}_2(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow 2 \text{NO}_2(\text{g})$
 - C. $2 \text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2 \text{CO}(\text{g})$
 - D. $\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$
 - E. $\text{CaO}(\text{s}) + \text{CO}(\text{g}) \rightarrow \text{CaCO}_3(\text{s})$
11. Considering intermolecular forces (dispersion, dipole, and hydrogen bonding), determine which molecule will have the highest boiling point.
- $\text{H}_2\text{S}, \text{H}_2\text{O}, \text{SO}_2, \text{SO}_3, \text{CO}_2$
- A. H_2S
 - B. H_2O
 - C. SO_2
 - D. SO_3
 - E. CO_2

12. A sample of seawater shows the $[\text{OH}^-]$ to be 2.0×10^{-6} M. What is the pH of this seawater sample?

- A. 8.30
- B. -8.30
- C. 5.70
- D. 6.99
- E. 7.53

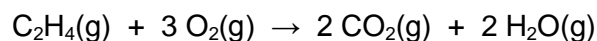
13. Which of the following formulas represent potassium dichromate?

- A. $\text{K}_2\text{Cr}_2\text{O}_7$
- B. $\text{K}_2(\text{Cr}_2\text{O}_7)_2$
- C. K_2CrO_4
- D. $\text{K}_2(\text{CrO}_4)_2$
- E. KCrO_4

14. Which of the following elements is most likely to form a molecule or ion that exceeds the octet rule?

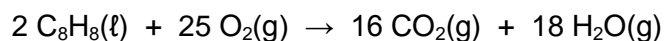
- A. Na
- B. S
- C. B
- D. F
- E. C

15. The combustion of ethylene proceeds by the reaction below. When the rate of disappearance of O_2 is 0.28 M/s, the rate of appearance of CO_2 is _____ M/s.



- A. 0.093
- B. 0.84
- C. 0.42
- D. 0.19
- E. 0.56

16. Give the percent yield when 28.16 g of CO_2 are formed from the reaction of 4.000 moles of octane with 8.000 moles of oxygen gas.



- A. 5.119%
- B. 20.00%
- C. 25.00%
- D. 50.00%
- E. 12.50%

17. Calculate the mass of a ball with a velocity of 40.0 m/s and a wavelength of 8.92×10^{-25} nm.

- A. 594 g
- B. 53.8 g
- C. 2.36 g
- D. 18.6 g
- E. 29.7 g

18. What mass of water ($k_f = 1.86 \text{ } ^\circ\text{C}/m$) is required to give an aqueous solution containing 0.265 mol of MgCl_2 a freezing point of $-3.8 \text{ } ^\circ\text{C}$? (Van't Hoff factor of MgCl_2 is 2.7)

- A. 0.538 kg
- B. 1.25 kg
- C. 0.113 kg
- D. 0.350 kg
- E. 0.882 kg

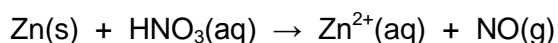
19. Which reaction below represents the second electron affinity of S?

- A. $\text{S}^{2-} \rightarrow \text{S}^{1-} + e^-$
- B. $\text{S}^{1-} + e^- \rightarrow \text{S}^{2-}$
- C. $\text{S} \rightarrow \text{S}^{1+} + e^-$
- D. $\text{S} + e^- \rightarrow \text{S}^{1-}$
- E. $\text{S}^{1-} \rightarrow \text{S} + e^-$

20. Which of the following compounds is most soluble in hexane (C_6H_{14})?

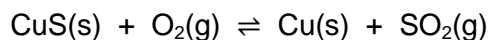
- A. 1-propanol
- B. 1-pentanol
- C. methanol
- D. 1-butanol
- E. ethanol

21. What are the coefficients in front of H_2O and NO when the redox reaction below is balanced under acidic conditions?

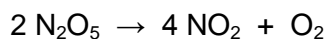


- A. $\text{H}_2\text{O} = 8$, $\text{NO} = 6$
- B. $\text{H}_2\text{O} = 10$, $\text{NO} = 7$
- C. $\text{H}_2\text{O} = 4$, $\text{NO} = 2$
- D. $\text{H}_2\text{O} = 1$, $\text{NO} = 3$
- E. $\text{H}_2\text{O} = 5$, $\text{NO} = 9$

22. Consider the reaction below. A reaction mixture initially contains 2.9 M O₂. Determine the equilibrium concentration of O₂ if K_c for the reaction is 1.5.



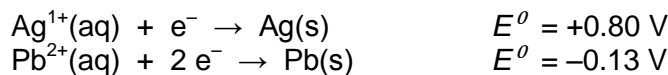
- A. 1.2 M
B. 1.7 M
C. 0.59 M
D. 1.9 M
E. 2.2 M
23. Determine the final value of n in a hydrogen atom transition, if the electron starts in $n = 1$ and the atom absorbs a photon of light with an energy of 2.044×10^{-18} J.
- A. 3
B. 6
C. 4
D. 5
E. 2
24. If a chemist wishes to prepare a buffer that will be effective at a pH of 3.00 at 25 ° C, the best choice would be an acid component with a K_a equal to_____.
- A. 9.10×10^{-10}
B. 9.10×10^{-2}
C. 9.10×10^{-6}
D. 9.10×10^{-8}
E. 9.10×10^{-4}
25. The decomposition of N₂O₅ is first order and has a rate constant of $4.82 \times 10^{-3} \text{ s}^{-1}$ at 64 ° C. If the reaction is initiated with 0.058 mol in a 1.00-L vessel, how many moles reacted after 151 s?



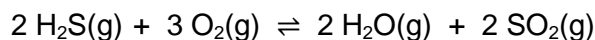
- A. 0.055 M
B. 0.028 M
C. 0.030 M
D. 12 M
E. 0.060 M

26. A scientist shines light with energy greater than the binding energy of platinum on a thin film of it. The same scientist then repeats the experiment with a higher intensity light. According to the photoelectric effect, what should be observed?
- A. Electrons are not ejected in the first experiment, but are in the second.
 - B. No electrons are ejected in either experiment.
 - C. Electrons are ejected in both experiments at the exact same time.
 - D. Electrons are ejected in both experiments, but the first experiment takes longer to eject electrons than the second.
 - E. Electrons are ejected in both experiments, but the second experiment takes longer to eject electrons than the first.
27. Why does an electron found in a 2s orbital have a lower energy than an electron found in a 2p orbital in multi-electron systems?
- A. There are more nodes found in the 2s orbital.
 - B. Electrons in the 2s orbital are shielded by electrons in the 2p.
 - C. The shape of the orbital ultimately determines the energy of the electrons.
 - D. The larger number of electrons in the 2p leads to greater repulsion.
 - E. Electrons in the 2s orbital can penetrate the 1s orbital and be closer to the nucleus.
28. Calculate the mole fraction of the total ions in an aqueous solution prepared by dissolving 0.400 moles of CaF_2 in 850.0 g of water.
- A. 0.00900
 - B. 0.00841
 - C. 0.0270
 - D. 0.0167
 - E. 0.0248
29. What is the stoichiometric coefficient for oxygen when the following equation is balanced using the lowest, whole-number coefficients?
- $$\text{C}_2\text{H}_6\text{O}(\ell) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{g})$$
- A. 3
 - B. 5
 - C. 7
 - D. 9
 - E. 6
30. Which element has the highest first ionization energy?
- A. Li
 - B. Be
 - C. B
 - D. Mg
 - E. Al

31. A galvanic cell consists of one half-cell that contains Ag(s) and Ag¹⁺(aq), and one half-cell that contains Pb(s) and Pb²⁺(aq). What species are produced at the electrodes under standard conditions?



- A. Pb(s) is formed at the cathode, and Ag¹⁺(aq) is formed at the anode.
 B. Pb²⁺(aq) is formed at the cathode, and Ag(s) is formed at the anode.
 C. Ag¹⁺(aq) is formed at the cathode, and Pb(s) is formed at the anode.
 D. Ag(s) is formed at the cathode, and Pb²⁺(aq) is formed at the anode.
 E. Ag(s) is formed at the cathode, and Pb(s) is formed at the anode.
32. Which element is diamagnetic?
- A. Zn
 B. V
 C. Rb
 D. Li
 E. F
33. Consider the following reaction at equilibrium. What effect will adding Ar to increase the total pressure have on the system?



- A. The reaction will shift to the right.
 B. No effect will be observed.
 C. The reaction will shift to the left.
 D. The equilibrium constant will decrease.
 E. The equilibrium constant will increase.
34. In which of the following sets are all species isoelectronic?
- A. Cl¹⁻, Ar, Ca²⁺
 B. Cr, Cr²⁺, Cr³⁺
 C. N, O²⁻, F¹⁻
 D. Sc³⁺, Y³⁺, La³⁺
 E. Mg¹⁺, Na, F¹⁻

35. All of the following relationships are true EXCEPT

- A. 0.328 g = 328 mg.
 B. 23 km < 4.5 x 10⁷ mm.
 C. 0.84 kg > 8.4 x 10⁴ mg.
 D. 41.3 mL > 8.72 x 10⁻² L.
 E. 1.3 nm = 1.3 x 10⁻⁶ mm.

36. Which of the following group of three contains a nonmetal, a metal, and a metalloid?

- A. Li, Al, Si
- B. Na, Hg, I
- C. I, Hg, Si
- D. K, O, Br
- E. H, Al, N

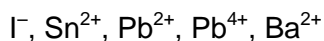
37. What is the percent composition of silicon and nitrogen in silicon nitride (Si_3N_4)?

- A. 30.21% Si and 69.79% N
- B. 42.92% Si and 57.08% N
- C. 54.03% Si and 45.97% N
- D. 60.06% Si and 39.94% N
- E. 69.40% Si and 30.60% N

38. Which of the following is the largest mass?

- A. 8.5×10^7 pg
- B. 1.5×10^8 ng
- C. 7.5×10^4 ng
- D. 6.5×10^2 mg
- E. 1.5×10^{-1} g

39. Which two of the ions below have the same number of electrons?



- A. I^- and Ba^{2+}
- B. I^- and Sn^{2+}
- C. Pb^{2+} and Ba^{2+}
- D. Sn^{2+} and Ba^{2+}
- E. Pb^{2+} and Pb^{4+}

40. An oxide of nitrogen contains 63.1% oxygen and has a molar mass of 76.0 g/mol. What is the molecular formula for the compound?

- A. N_2O
- B. NO
- C. NO_2
- D. N_2O_3
- E. N_2O_5

