2020 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

1A	2A											3A	4A	5A	6A	7A	8A
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 65.38	31 Ga 69.72	32 Ge 72.59	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 180.9	74 W 183.9	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	89 Ac** (227)	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une									

*Lanthanides	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
**Actinides	90 Th 232.0	91 Pa (231)	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 (260)

Potentially Useful Information

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

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

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

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

$P_{solvent} = X_{solvent} \bullet P°_{solvent}$

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

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

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

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

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

$\ln\left(\frac{K_2}{K_1}\right) = \frac{-\Delta H_{rxn}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$

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

$pH = -\log [H_3O^+]$

$pOH = -\log [OH^-]$

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

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

$\Delta G° = \Delta H° - T\Delta S°$

$E_{cell}° = E_{red}° + E_{ox}°$

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

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

$\Delta G° = -nF\varepsilon°$

$c = \lambda\nu$

$\Pi = MRT$

$\Delta E = h\nu$

$F = 96485$ C/mol

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

$R = 0.08206$ L atm/mol K; 8.3145 J/mol K

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

1.0 kg = 2.2 lb

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

1.0 in = 2.54 cm

1 atm = 101,325 Pa = 1.01325 bar

1 lb = 453.59 g

1 J = 1 N • m = 1 kg • m^2 • s^{-2} = 0.239 cal

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

$h = 6.626 \times 10^{-34}$ J·s

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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1. The ability to dissolve in a solvent is also called

   A. solubility B. volatility C. malleability D. molarity E. polarizability

2. Write the formula for copper(II) sulfate pentahydrate.

   A. $Cu_2SO_3 \cdot H_5$ B. $Cu_2S \cdot H_2O$ C. $CuS \cdot 5H_2O$ D. $(CuSO_4)_5$ E. $CuSO_4 \cdot 5H_2O$

3. Identify the number of electron groups around a molecule with sp hybridization.

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

4. What is the specific heat capacity of an alloy that requires 59.3 kJ to raise the temperature of 150.0 g of the alloy from 298 K to 398 K?

   A. 4.38 J/g.°C
   B. 2.29 J/g.°C
   C. 3.95 J/g.°C
   D. 2.53 J/g.°C
   E. 1.87 J/g.°C

5. Arrange the following substances in order of **decreasing** boiling point.

   H_2O N_2 CO

   A. $CO > H_2O > N_2$
   B. $N_2 > CO > H_2O$
   C. $CO > N_2 > H_2O$
   D. $H_2O > CO > N_2$
   E. $N_2 > H_2O > CO$

6. Which of the following species is amphoteric?

   A. CO_3^{2-} B. HF C. NH_4^+ D. HPO_4^{2-} E. H_3PO_4

7. A syringe initially holds a sample of gas with a volume of 285 mL at 355 K and 1.88 atm. To what temperature must the gas in the syringe be heated/cooled in order to have a volume of 435 mL at 2.50 atm?

   A. 139 K
   B. 572 K
   C. 175 K
   D. 466 K
   E. 721 K

8. Identify the missing particle in the following nuclear equation:

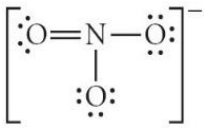
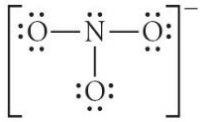
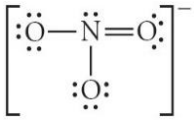
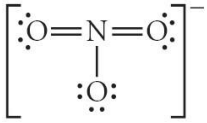
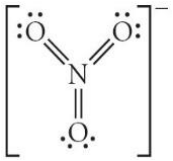
$$^{228}_{90}\text{Th} \rightarrow {}^{4}_{2}\text{He} + ?$$

   A. $^{232}_{92}\text{U}$ B. $^{232}_{89}\text{Ac}$ C. $^{228}_{89}\text{Ac}$ D. $^{228}_{88}\text{Ra}$ E. $^{224}_{88}\text{Ra}$

9. What is the chemical name for P_2I_4?

   A. phosphorous(IV) iodine
   B. diphosphorous tetraiodide
   C. phosphorous tetraiodine
   D. phosphorous(II) iodine
   E. diphosphorous iodine

10. Which of the following is the best Lewis structure for NO_3^-?

A.  B.  C.  D.  E. 

11. For a given compound, list the decreasing order of entropy for a liquid, solid, and gas.

   A. solid > gas > liquid
   B. liquid > solid > gas
   C. gas > liquid > solid
   D. gas > solid > liquid
   E. solid > liquid > gas

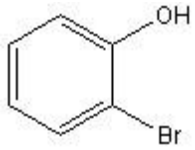
12. What is the triple point?

A. The temperature, pressure, and density for a gas.
B. The temperature at which the boiling point equals the melting point.
C. The temperature and pressure where liquid, solid, and gas are equally stable and are in equilibrium.
D. The temperature that is unique for a substance.
E. The temperature at which the solid and liquid co-exist.

13. What is the concentration of hydroxide ions in pure water at certain temperature if K_W has a value of 1.57×10^{-14}?

A. 1.25×10^{-7} M
B. 1.00×10^{-7} M
C. 1.30×10^{-7} M
D. 1.47×10^{-7} M
E. 8.93×10^{-8} M

14. Name the following compound.



A. 2-bromophenol
B. 2-bromoaniline
C. 2-bromonaphthalene
D. 2-bromotoluene
E. 2-bromoanisole

15. Which element listed would be the best fit for the following ionization energies (all in kJ/mol)?

IE_1 = 1012 IE_2 = 1900 IE_3 = 2910 IE_4 = 4960 IE_5 = 6270 IE_6 = 22,200

A. S B. Si C. Cℓ D. Mg E. P

16. Select the complete electron configuration for Cu^+.

A. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8$
B. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^9$
C. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$
D. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$
E. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^9$

17. The Henry's Law constant of methyl bromide, CH_3Br, is 0.159 M/atm at 25 ^{0} C. What is the solubility of methyl bromide in water at 25 ^{0} C and at a partial pressure of 270. mmHg?

    A. 0.448 M
    B. 0.0564 M
    C. 0.355 M
    D. 42.9 M
    E. 0.641 M

18. How many molecules of HCℓ are formed when 90.0 g of water reacts according to the following balanced reaction? Assume excess $ICℓ_3$.

$$2\ ICℓ_3\ +\ 3\ H_2O\ \rightarrow\ ICℓ\ +\ HIO_3\ +\ 5\ HCℓ$$

    A. 3.00×10^{24} molecules
    B. 5.00×10^{24} molecules
    C. 5.00×10^{25} molecules
    D. 6.00×10^{24} molecules
    E. 9.00×10^{24} molecules

19. Determine the mass of a ball with a velocity of 40.0 m/s and a wavelength of 8.92×10^{-34} m.

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

20. For the reaction, the value of K_C is 8.3×10^{-10} at 25 ^{0} C. What is the concentration of N_2 gas at equilibrium when the concentration of NO_2 is twice the concentration of O_2 gas?

$$N_2(g)\ +\ 2\ O_2(g)\ \leftrightarrow\ 2\ NO_2(g)$$

    A. 2.4×10^{9} M
    B. 2.1×10^{-10} M
    C. 4.2×10^{-10} M
    D. 8.3×10^{-10} M
    E. 4.8×10^{9} M

21. Calculate the mole fraction of the total ions in an aqueous solution prepared by dissolving 0.400 moles of calcium fluoride in 850.0 g of water.

    A. 0.00841
    B. 0.0270
    C. 0.0167
    D. 0.0248
    E. 0.00900

22. According to Hund's Rule

    A. Electrons fill degenerate orbitals singly and pair up only after all the orbitals are half filled.
    B. Electrons found in the same orbital must have opposite spins.
    C. No two electrons in the same atom can have the same set of four quantum numbers.
    D. Electrons pair off first, then fill orbitals.
    E. Low energy orbitals fill before high energy orbitals.

23. How many photons are contained in a burst of yellow light (589 nm) from a sodium lamp that contains 616 kJ of energy?

    A. 4.03×10^{28} photons
    B. 2.08×10^{13} photons
    C. 1.83×10^{24} photons
    D. 2.48×10^{25} photons
    E. 3.06×10^{30} photons

24. At a certain temperature, K_C equals 1.4×10^2 for the reaction:

$$2\ CO(g)\ +\ O_2(g)\ \leftrightarrow\ 2\ CO_2(g)$$

    If a 3.50 L flask contains 0.400 mol of CO_2 and 0.100 mol of O_2 at equilibrium, how many moles of CO are also present in the flask?

    A. 0.200 mol
    B. 0.0114 mol
    C. 0.700 mol
    D. 0.107 mol
    E. 0.0571 mol

25. Aluminum metal reacts with aqueous iron(III) oxide to form aqueous aluminum oxide and iron metal. What is the stoichiometric coefficient for aluminum when the chemical equation is balanced using the lowest, whole-number stoichiometric coefficients?

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

26. Choose the aqueous solution with the **highest** freezing point. These are all solutions of nonvolatile solutes.

    A. 0.200 *m* $Mg(C\ell O_4)_2$
    B. 0.200 *m* $Ba(NO_3)_2$
    C. 0.200 *m* $HOCH_2CH_2OH$
    D. 0.200 *m* Na_3PO_3
    E. These all have the same freezing point.

27. Place the following in order of increasing radius.

    Br^{1-} Na^{1+} Rb^{1+}

    A. $Rb^{1+} < Br^{1-} < Na^{1+}$
    B. $Br^{1-} < Na^{1+} < Na^{1+}$
    C. $Rb^{1+} < Na^{1+} < Br^{1-}$
    D. $Na^{1+} < Rb^{1+} < Br^{1-}$
    E. $Br^{1-} < Na^{1+} < Rb^{1+}$

28. A chemist transfers a volume of water from a pipette to a small, clean beaker and weighs it on an analytical balance. She then repeats this exercise for a total of 10 trials. She then calculates the standard deviation to see how close the values are to each other. What is the main point of this exercise?

    A. To determine the maximum capacity of the pipette
    B. To evaluate the precision of the pipette
    C. To determine the number of significant digits she should use for volumes
    D. To verify the maximum reliable capacity of the pipette
    E. To evaluate the accuracy of the pipette

29. What is the length of a perfect cube with a volume of 1000 mL?

    A. 0.01 cm
    B. 0.1 cm
    C. 1 cm
    D. 10 cm
    E. 1,000 cm

30. Which of the following represents the correct number of subatomic particles for the neutral isotope $^{32}_{15}\mathrm{P}$?

    A. 32 e^-; 32 n^o; 15 p^+
    B. 15 e^-; 32 n^o; 17 p^+
    C. 15 e^-; 17 n^o; 15 p^+
    D. 32 e^-; 17 n^o; 15 p^+
    E. 15 e^-; 15 n^o; 17 p^+

31. How many total atoms are in a single formula unit of ammonium phosphate?

A. 2
B. 7
C. 10
D. 20
E. 25

32. Elemental analysis of an unknown compound revealed it was 25.0% carbon, 8.30% hydrogen, and 66.7% oxygen by mass. What is the empirical formula for this compound?

A. C_3HO_8
B. CHO_2
C. CHO
D. $C_4H_{16}O_8$
E. CH_4O_2

33. What is the percent composition of oxygen in methanol?

A. 0.170%
B. 0.500%
C. 16.7%
D. 50.0%
E. 83.3%

34. An acetate buffer prepared from equimolar concentrations of acetic acid and sodium acetate would have a pH of 4.76. What would the ratio of acetate to acetic acid ($C_2H_3O_2^-$: $HC_2H_3O_2$) be if the pH was adjusted to 3.76 with HCℓ?

A. 1:10
B. 10:1
C. 1:2
D. 2:1
E. 1:1

35. The decomposition of ozone into oxygen has the rate law expressed below. What would be the effect on rate if the concentrations of both ozone and oxygen gas are doubled?

$$\text{rate} = k\,\frac{[O_3]^2}{[O_2]}$$

A. The rate would quadruple.
B. The rate would decrease by one half.
C. The rate would increase by 1.5 times.
D. The rate would decrease by 1.5 times.
E. The rate would double.

36. A chemical reaction has a ΔG value of –14.9 kJ/mol. How would adding a metal catalyst affect the free energy values of the reactants and products?

A. There would be no change in these values.
B. The free energy of the reactants would increase.
C. The free energy of the reactants would decrease.
D. The free energy of the products would increase.
E. The free energy of the products would decrease.

37. Solutions to the Schrodinger equation tell us which of these?

A. The number of electrons an atom may have.
B. The way in which electrons in an atom will be distributed in space around the nucleus.
C. The number of orbitals and shells an atom may have that can be occupied by electrons.
D. The number of subatomic particles of each type that may be present in an atom.
E. The uncertainty we are about the position of a subatomic particle when we know its momentum with increasing certainty.

38. Which of the following is a possible set of quantum numbers for an electron in the 2p orbital in a ground state nitrogen atom?

A. $n = 2;\ \ell = 1;\ m_\ell = 2;\ m_s = ½$
B. $n = 2;\ \ell = 1;\ m_\ell = 0,\ m_s = –½$
C. $n = 1;\ \ell = 1;\ m_\ell = 0;\ m_s = ½$
D. $n = 3;\ \ell = 0;\ m_\ell = 0;\ m_s = –½$
E. $n = 1;\ \ell = 0;\ m_\ell = 0;\ m_s = ½$

39. In a standard galvanic cell, ions will flow across the salt bridge in which direction?

A. Cations and anions both flow from anode to cathode.
B. Cations and anions both flow from cathode to anode.
C. Cations flow from anode to cathode while anions move in the opposite direction.
D. Anions flow from anode to cathode while cations move in the opposite direction.
E. The direction will vary depending on whether the cell is under standard or non-standard conditions.

40. Given the standard reduction potentials shown, which of these substances would be the strongest reducing agent?

$Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s)$	+0.34 V
$Sn^{4+}(aq) + 2\ e^- \rightarrow Sn^{2+}(aq)$	+0.15 V
$2\ H^+(aq) + 2\ e^- \rightarrow H_2(g)$	0.00 V
$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq)$	–0.26 V
$Fe^{2+}(aq) + 2\ e^- \rightarrow Fe(s)$	–0.44 V

A. $Cu^{2+}(aq)$ B. Cu(s) C. Fe(s) D. $Fe^{2+}(aq)$ E. $H_2(g)$