Worldwide Youth in Science and Engineering

# 2013 Academic Challenge

## CHEMISTRY TEST  -  STATE FINAL

### This  Test  Consists  of  40  Questions

**Chemistry Test Production Team**
Doug Mulford, Emory University – Author/Team Leader
Tracy Morkin, Emory University – Author
Nancy Carter Dopke, Alma College – Reviewer
Mary Weaver, WYSE – Coordinator of Test Production

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.  Only one oval should be marked to answer each question.  Multiple ovals will automatically be graded as incorrect answers.

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  \*\*\***

**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<br>H<br>1.008 | | | | | | | | | | | | | | | | | 2<br>He<br>4.003 |
| 3<br>Li<br>6.941 | 4<br>Be<br>9.012 | | | | | | | | | | | 5<br>B<br>10.81 | 6<br>C<br>12.01 | 7<br>N<br>14.01 | 8<br>O<br>16.00 | 9<br>F<br>19.00 | 10<br>Ne<br>20.18 |
| 11<br>Na<br>22.99 | 12<br>Mg<br>24.31 | | | | | | | | | | | 13<br>Al<br>26.98 | 14<br>Si<br>28.09 | 15<br>P<br>30.97 | 16<br>S<br>32.07 | 17<br>Cl<br>35.45 | 18<br>Ar<br>39.95 |
| 19<br>K<br>39.10 | 20<br>Ca<br>40.08 | 21<br>Sc<br>44.96 | 22<br>Ti<br>47.88 | 23<br>V<br>50.94 | 24<br>Cr<br>52.00 | 25<br>Mn<br>54.94 | 26<br>Fe<br>55.85 | 27<br>Co<br>58.93 | 28<br>Ni<br>58.69 | 29<br>Cu<br>63.55 | 30<br>Zn<br>65.38 | 31<br>Ga<br>69.72 | 32<br>Ge<br>72.59 | 33<br>As<br>74.92 | 34<br>Se<br>78.96 | 35<br>Br<br>79.90 | 36<br>Kr<br>83.80 |
| 37<br>Rb<br>85.47 | 38<br>Sr<br>87.62 | 39<br>Y<br>88.91 | 40<br>Zr<br>91.22 | 41<br>Nb<br>92.91 | 42<br>Mo<br>95.94 | 43<br>Tc<br>(98) | 44<br>Ru<br>101.1 | 45<br>Rh<br>102.9 | 46<br>Pd<br>106.4 | 47<br>Ag<br>107.9 | 48<br>Cd<br>112.4 | 49<br>In<br>114.8 | 50<br>Sn<br>118.7 | 51<br>Sb<br>121.8 | 52<br>Te<br>127.6 | 53<br>I<br>126.9 | 54<br>Xe<br>131.3 |
| 55<br>Cs<br>132.9 | 56<br>Ba<br>137.3 | 57<br>La*<br>138.9 | 72<br>Hf<br>178.5 | 73<br>Ta<br>180.9 | 74<br>W<br>183.9 | 75<br>Re<br>186.2 | 76<br>Os<br>190.2 | 77<br>Ir<br>192.2 | 78<br>Pt<br>195.1 | 79<br>Au<br>197.0 | 80<br>Hg<br>200.6 | 81<br>Tl<br>204.4 | 82<br>Pb<br>207.2 | 83<br>Bi<br>209.0 | 84<br>Po<br>(209) | 85<br>At<br>(210) | 86<br>Rn<br>(222) |
| 87<br>Fr<br>(223) | 88<br>Ra<br>226 | 89<br>Ac**<br>(227) | 104<br>Unq | 105<br>Unp | 106<br>Unh | 107<br>Uns | 108<br>Uno | 109<br>Une | | | | | | | | | |

| *Lanthanides | 58<br>Ce<br>140.1 | 59<br>Pr<br>140.9 | 60<br>Nd<br>144.2 | 61<br>Pm<br>(145) | 62<br>Sm<br>150.4 | 63<br>Eu<br>152.0 | 64<br>Gd<br>157.3 | 65<br>Tb<br>158.9 | 66<br>Dy<br>162.5 | 67<br>Ho<br>164.9 | 68<br>Er<br>167.3 | 69<br>Tm<br>168.9 | 70<br>Yb<br>173.0 | 71<br>Lu<br>175.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Actinides | 90<br>Th<br>232.0 | 91<br>Pa<br>(231) | 92<br>U<br>238.0 | 93<br>Np<br>(237) | 94<br>Pu<br>(244) | 95<br>Am<br>(243) | 96<br>Cm<br>(247) | 97<br>Bk<br>(247) | 98<br>Cf<br>(251) | 99<br>Es<br>(252) | 100<br>Fm<br>(257) | 101<br>Md<br>(258) | 102<br>No<br>(259) | 103<br>Lr<br>(260) |

**Potentially Useful Information**

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

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

$P_{solvent} = C_{solvent} \bullet P^\circ_{solvent}$

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

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

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

pH = -log [H$_3$O$^+$]

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

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

$\Delta E = B\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_{fi}^2}\right)$

$\Delta G^\circ = nF\varepsilon^\circ$

F = 96485 C/mol

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

1.0 kg = 2.2 lb

1.0 in = 2.54 cm

1 lb = 453.59 g

c = 2.998 × 10$^8$ m/s

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

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

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

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

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

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

pOH = -log [OH$^-$]

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

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

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

K$_w$ = 1.0 × 10$^{-14}$

B = -2.18x10$^{-18}$ J

N$_A$ = 6.022x10$^{23}$

1 atm = 101,325 Pa = 1.01325 bar

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

c = $\lambda\nu$

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.

1.  An atom of element number 33 (As) is in its ground electronic state. Which one of the following sets of quantum numbers could not apply to any of its electrons?

    A.  $n = 2; l = 1 ; m_l = -1, m_s = +\frac{1}{2}$
    B.  $n = 3; l = 0 ; m_l = 0, m_s = -\frac{1}{2}$
    C.  $n = 3; l = 2 ; m_l = 2, m_s = +\frac{1}{2}$
    D.  $n = 4; l = 0 ; m_l = 0, m_s = -\frac{1}{2}$
    E.  $n = 4; l = 2 ; m_l = -2, m_s = +\frac{1}{2}$

2.  Which one of the following has a Lewis structure most like that of $NO^+$?

    A.  $NO_2^+$          B.  $O_2^{2-}$          C.  $O_2^{2+}$          D.  $NO$          E.  $NO^-$

3.  A reaction occurs between sodium carbonate and hydrochloric acid producing sodium chloride, carbon dioxide, and water. The correct set of coefficients, respectively, for the balanced reaction is:

    A.  3  6  6  3  4
    B.  8  6  5  10  5
    C.  5  10  10  5  5
    D.  1  2  2  1  1
    E.  none of these

4.  Phosphorus has the molecular formula $P_4$, and sulfur has the molecular formula $S_8$. How many grams of phosphorus contain the same number of atoms as 2.97 g of sulfur?

    A.  1.43 g          B.  0.697 g          C.  2.87 g          D.  2.97 g          E.  None of these

5.  Which of the following will be a buffer when dissolved in 1.0 L of water?

    A.  0.2 mol HCl and 0.1 mol NaOH
    B.  0.2 mol HBr and 0.1 mol NaOH
    C.  0.2 mol HCl and 0.4 mol $NH_3$
    D.  0.3 mol HCl and 0.3 mol KCl
    E.  0.2 mol $CH_3COOH$ and 0.4 mol NaOH

6.  Antimony (Latin *stibium*) was one of the elements known to the alchemists. Two antimony isotopes occur naturally: $^{121}Sb$ (isotopic mass 120.904 amu) and $^{123}Sb$ (isotopic mass 122.904 amu). If the atomic mass of antimony is 121.76 amu, what is the natural abundance of $^{121}Sb$?

    A.  25.0%          B.  42.8%          C.  50.0%          D.  57.2%          E.  None of these

7.  The decomposition of lead(II) nitrate produces PbO, $NO_2$ and $O_2$ with a 71.5% yield. If you need to produce 12.45 g of $NO_2$, how much lead(II) nitrate must you start with?

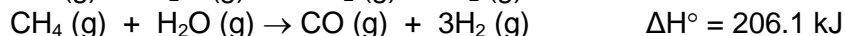    A.  32.1 g          B.  44.8 g          C.  62.7 g          D.  89.6 g          E.  125 g
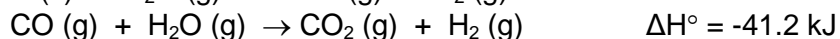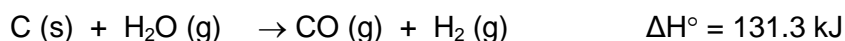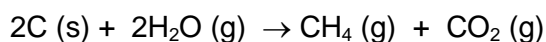
8.   Which of the following statements is true about the ionization energy of $Mg^+$?

     A.  It will be equal to the ionization energy of Li.
     B.  It will be equal to and opposite in sign to the electron affinity of Mg.
     C.  It will be equal to and opposite in sign to the electron affinity of $Mg^+$.
     D.  It will be equal to and opposite in sign to the electron affinity of $Mg^{2+}$.
     E.  None of the above.

9.   If a solution is 0.010 M with respect to $Mg^{2+}$, what is the maximum hydroxide concentration that would be present without causing the precipitation of $Mg(OH)_2$?
     ($K_{sp}$ $Mg(OH)_2$ = $1.2 \times 10^{-11}$)

     A.  $1.2 \times 10^{-9}$ M         B.  $1.8 \times 10^{-5}$ M      C.  $3.5 \times 10^{-6}$ M      D.  $3.5 \times 10^{-5}$ M      E.  $1.4 \times 10^{-4}$ M

10.  A particular metal in a photoelectric cell has a threshold energy that corresponds to a photon of 500 nm.  Which of the following statements is **incorrect**?

     A.  If the metal is irradiated with 600 nm light, no electrons will be ejected.
     B.  If the metal is irradiated with 250 nm light, twice as many electrons will be ejected than if it was irradiated with 500 nm light.
     C.  If the metal is irradiated with 450 nm light, the ejected electrons will have a greater kinetic energy than if the metal was irradiated with 500 nm light.
     D.  If the metal is irradiated with 500 nm light with an increased intensity, more electrons will be ejected.
     E.  If the metal is irradiated with 10 photons of 500 nm light then 10 electrons will be ejected.

11.  You have 30.8 g of $O_2$ gas in flask A.  Flask A is twice the volume of Flask B, which contains $CO_2$ gas.  The pressure and temperature of both containers are the same. Calculate the mass of carbon dioxide in Flask B.

     A.  0.481 g              B.  1.93 g              C.  21.2 g              D.  42.4 g              E.  none of  the above

12.  The rate constant for the reaction shown below is 8.0 $M^{-3}$ $s^{-1}$ at 25°C.  The reaction is first order in $BrO_3^-$ and first order in $Br^-$.  What is the order with respect to $H^+$?

     $$BrO_3^-\ (aq)\ +\ 5Br - (aq)\ +\ 6H^+\ \rightleftarrows\ 3Br_2\ (l)\ +\ 3H_2O\ (l)$$

     A.  1st order              B.  2nd order          C.  3rd order          D.  4th order          E.  5th order

13.  Which compound would be expected to be the least soluble in water?

     A.  $CH_3CH_2CH_2F$
     B.  $CH_3CH_2CH_2NH_2$
     C.  $CH_3CH_2CH(OH)CH_3$
     D.  $CH_3CH_2COOH$
     E.  $CH_3CH_2NHCH_3$

14. Which of the following statements is true?

    A. The Kr 1s orbital is smaller than the He 1s orbital because Kr's p and d orbitals crowd the s orbitals.
    B. The Kr 1s orbital is larger than the He 1s orbital because Kr contains more electrons.
    C. The Kr 1s orbital is smaller than the He 1s orbital because Kr's nuclear charge draws the electrons closer.
    D. The Kr 1s orbital and the He 1s orbital are the same size because they are both s orbitals in the n=1 shell.
    E. The Kr 1s orbital is larger than the He 1s orbital because Kr's ionization energy is lower so it is easier to remove electrons.

15. What is the ratio of A to B in the following equation if 43.7 mL of 0.731 $M$ A requires 25.8 mL of 0.412 $M$ B to be titrated completely?

    $$\_\_A + \_\_B \rightarrow C$$

    A. 1:1          B. 2:3          C. 3:1          D. 1:3          E. 3:3

16. A saturated solution of $PbBr_2$ is prepared by dissolving the solid salt in water. The concentration of $Br^-$ in the solution is found to be 0.023 M. What is the Ksp for $PbBr_2$?

    A. $6.1 \times 10^{-6}$          B. $1.2 \times 10^{-5}$          C. $4.9 \times 10^{-5}$          D. $2.6 \times 10^{-4}$          E. $2.3 \times 10^{-2}$

17. Using the following data, calculate the heat of reaction for the coal gasification process:

    $$2C\ (s) + 2H_2O\ (g) \rightarrow CH_4\ (g) + CO_2\ (g)$$

    | | |
    |---|---|
    | $C\ (s) + H_2O\ (g) \rightarrow CO\ (g) + H_2\ (g)$ | $\Delta H° = 131.3$ kJ |
    | $CO\ (g) + H_2O\ (g) \rightarrow CO_2\ (g) + H_2\ (g)$ | $\Delta H° = -41.2$ kJ |
    | $CH_4\ (g) + H_2O\ (g) \rightarrow CO\ (g) + 3H_2\ (g)$ | $\Delta H° = 206.1$ kJ |

    A. -378.6 kJ          B. -157.2 kJ          C. -116.0 kJ          D. 15.3 kJ          E. 378.6 kJ

18. Nitrogen dioxide can dissociate to nitric oxide and oxygen.

    $$2NO_2(g) \rightleftarrows 2NO(g) + O_2(g) \qquad \Delta H°rxn = +114\ kJ$$

    Under which reaction conditions would you expect to produce the largest amount of oxygen?

    A. high temperature, high pressure
    B. low temperature, high pressure
    C. high temperature, low pressure
    D. low temperature, low pressure
    E. You need to know the equilibrium constant to make the prediction

19. A 1.35 m aqueous solution of compound X had a boiling point of 101.4 °C. Which one of the following could be compound X? The boiling point elevation constant for water is 0.52 °C/m.

    A. $CH_3CH_2OH$          B. $C_6H_{12}O_6$          C. $Na_3PO_4$          D. KCl          E. $CaCl_2$

20. What is the atomic weight of an element if 4.00 grams of it contains 2.98 x $10^{22}$ atoms?

    A.  20.2 u            B.  80.8 u           C.  19.7 u           D.  8.08 u           E.  None of these

21. Calculate the vapor pressure of a solution made by dissolving 109 grams of glucose (molar mass = 180.2 g/mol) in 920.0 ml of water at 25 °C. The vapor pressure of pure water at 25 °C is 23.76 mm Hg. Assume the density of the solution is 1.00 g/ml.

    A.  0.278 mm Hg
    B.  0.605 mm Hg
    C.  23.0 mm Hg
    D.  23.5 mm Hg
    E.  23.8 mm Hg

22. You have equal masses of different solutes in equal volumes of solution.  Which of the solutes would make the solution having the highest molar concentration?

    A.  NaOH           B.  KCl           C.  KOH           D.  LiOH           E.  All would be the same

23. A 70.28-g sample of $Ba(OH)_2$ is dissolved in enough water to make 2.300 L of solution.  How many mL of this solution must be diluted with water in order to make 1.000 L of 0.100 M $Ba(OH)_2$?

    A.  561 mL           B. 244 mL           C. 178 mL           D. 17.8 mL           E. 4.10 mL

24. The rate constant for a reaction at 40°C is exactly 3 times that at 20°C.  What is the activation energy for the reaction?

    A.  9.13 kJ/mol
    B.  5.04 kJ/mol
    C.  41.9 kJ/mol
    D.  3.00 kJ/mol
    E.  none of these

25. What is the best estimate of the [Cl⁻] ion concentration when 50.0 mL of 0.100 M $CaCl_2$ and 1.00 g AgCl(s) are mixed?

    A.  0.00500M
    B.  0.0500 M
    C.  0.200 M
    D.  0.339 M
    E.  0.450 M

26. Compare a liter of carbon dioxide to a liter of hydrogen gas, with both gases at 25 °C and 2 atm. Which statement is correct?

    A.  The $CO_2$ and $H_2$ molecules have the same total mass.
    B.  There are more molecules of $H_2$ than $CO_2$ present.
    C.  The $CO_2$ and $H_2$ molecules hit the walls of the containers with the same frequency.
    D.  The $CO_2$ molecules are on the average moving slower than the $H_2$ molecules.
    E.  The average kinetic energy of the $CO_2$ molecules is greater than that of the $H_2$ molecules.

27. Which of the following molecules is paramagnetic?

    A. $Sc^{3+}$　　　　　B. $Mn^{2+}$　　　　　C. Zn　　　　　D. $Zn^{2+}$　　　　　E. $Al^{3+}$

28. Give the IUPAC name for the following compound:

    A. 1-chloro-2-methylcyclohexane
    B. 1-methyl-2-chlorocyclohexane
    C. 1-chloro-5-methylcyclohexane
    D. 1-methyl-5-chlorocyclohexane
    E. 1,2-chloromethylcyclohexane
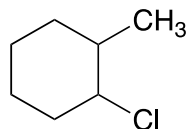
29. For a process with $\Delta S < 0$ J/K mol, which of the following statements is correct?

    A. The process will be spontaneous if $\Delta H < 0$ kJ.
    B. The process will be spontaneous if $\Delta H < T\Delta S$.
    C. The process can never be spontaneous.
    D. The process will be spontaneous, regardless of $\Delta H$.
    E. The process will be spontaneous as long as $\Delta S_{surr} > 0$ J/K mol.

30. What is the molecular shape of $ClF_2^+$?

    A. Linear
    B. B. trigonal planar
    C. C. tetrahedral
    D. D. bent
    E. E. none of these

31. Which of the following are evidence for a chemical change?

    I.　　Formation of a new compound
    II.　　Evaporation of a liquid
    III.　　Change of odor
    IV.　　Color change
    V.　　Melting

    A. I, II, IV, V
    B. II, V
    C. I, III, IV
    D. I, II
    E. All of the above

32. A molecule contains 76.34% carbon, 6.41% hydrogen, and 17.25% fluorine. Each molecule contains one fluorine atom. What is the total number of carbon, hydrogen, and fluorine atoms in one molecule?

    A. 8　　　　　B. 12　　　　　C. 13　　　　　D. 14　　　　　E. 15

USE THE STANDARD POTENTIALS BELOW FOR THE QUESTIONS 33 AND 34.

$Cu^{2+} + 2e^- \rightarrow Cu$          $E° = 0.339$ V
$Pb^{2+} + 2e^- \rightarrow Pb$          $E° = -0.130$ V
$Ni^{2+} + 2e^- \rightarrow Ni$          $E° = -0.250$ V

33. For a voltaic cell employing the Cu and Pb half-reactions with $Cu(NO_3)_2$ and $Pb(NO_3)_2$, respectively, calculate the maximum amount of work that would accompany the reaction of one mole of lead under standard conditions.

A. -40.3 kJ
B. -45.3 kJ
C. -90.5 kJ
D. No work can be done. The system is at equilibrium.
E. None of the above.

34. Which of the following metals would dissolve in stomach acid?

A. Cu, Pb, and Ni
B. Pb and Ni
C. Cu
D. Cu and Pb
E. None

35. Sulfuric acid may be produced by the following process:

$$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$$
$$2SO_2 + O_2 \rightarrow 2SO_3$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$
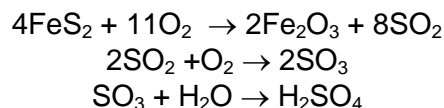
How many moles of $H_2SO_4$ will be produced from 5.62 moles of $FeS_2$ assuming each step is 100% efficient?

A. 1.40 mol
B. 2.81 mol
C. 5.62 mol
D. 11.2 mol
E. 30.9 mol

36. The base dissociation constant, $K_b$, equals $7.9 \times 10^{-13}$ for $SO_4^{2-}$ and the $K_a$ is $1.78 \times 10^{-5}$ for $NH_4^+$. Which statement about the following equilibrium is correct?

$$HSO_4^-(aq) + NH_3(aq) \rightleftarrows SO_4^{2-}(aq) + NH_4^+(aq)$$

A. The initial concentrations of the hydrogen sulfate ion and ammonia must be known before any prediction can be made.
B. The reactants will be favored because ammonia is a stronger base than the sulfate anion.
C. Neither reactants or products will be favored because all of the species are weak acids or bases.
D. The products will be favored because the hydrogen sulfate ion is a stronger acid than the ammonium ion.
E. Once equilibrium is established the pH will be neutral.

37. Silver crystallizes in a face-centered cubic system. If the edge of the unit cell is 407 pm, what is the radius of a silver atom?

   A. 144 pm          B. 176 pm          C. 204 pm          D. 288 pm          E. 352 pm

38. $^{64}Co$ decays by a first-order process via the emission of a beta particle. The $^{64}Co$ isotope has a half-life of 7.8 min. How long will it take for 31/32 of the cobalt to undergo decay?

   A. 7.8 min.          B. 16 min.          C. 23 min.          D. 31 min.          E. 3 9 min.

39. Which of the following have atoms that do not all lie in the same plane?

   A. $C_2H_4$
   B. $N_2F_4$
   C. $COCl_2$
   D. $H_2CCCH_2$
   E. There is more than one of A-D with atoms that do not lie in the same plane.

40. Consider the Lewis structure $CH_3CHNH$. What orbital is the lone pair on nitrogen located in?

   A. s          B. p          C. sp          D. $sp^2$          E. $sp^3$