The 55th Annual
Merck State Science Day Competition
May 17, 2005

Chemistry

Directions:
PLEASE DO NOT OPEN THE EXAM BOOKLET UNTIL DIRECTED.

Be sure to fill in your name on the answer sheet both by printing it in the correct space, and by filling in the corresponding letter in the provided spaces.

Use a #2 pencil only.

Carefully erase any errors, and do not make any extraneous marks on the answer sheet.
Do NOT use *White-Out* on any portion of the answer sheet.

The test has <u>55 items</u>. You have **90** minutes in which to answer all the questions.

There is only one correct answer per question. Do not spend too much time on any one question. Do the items you find easier first, and then go back to those you find more difficult or time consuming during the time you have remaining. Your individual score will be computed on the basis of the number of correctly answered items. (There is no penalty for guessing.)

In addition to the periodic table, there are several subject-specific items below that you may find useful in answering certain questions. Be sure to read them.

INFORMATION THAT MAY BE USEFUL IN SOLVING THE PROBLEMS

Universal gas constant: $R = 0.0821$ atm-liter/(mole-K) $R = 8.31$ kPa-liter/(mole-K)	$1 dm^3 = 1$ L PV=nRT Specific heat $_{H2O} = 4.18$ J/g°C
1 Faraday ($\mathfrak{I}$) = 96,500 coulombs/mole **= 96,500 joules/volt** **1 electron volt/atom = 96.5 kilojoules/mole**	1 calorie = 4.184 joules $Q = mc\Delta T$ $KE_{ave} = \frac{1}{2}mv^2$
Speed of light in vacuum = 3.00×10^8 m/sec **Planck's constant, h = 6.63×10^{-34} joule-sec** **Boltzmann's constant, k = 1.38×10^{-23} joule/K** **Avogadro's number = 6.03×10^{23} molecules/mole**	K_f water = 1.86 °C/m K_b water = 0.51°C/m

MERCK State Science Day 2005   Chemistry

Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. When 50.0 mL of 1.00 M HCl solution is mixed with 50.0 mL of 1.00 M KOH solution, the temperature of the mixed solutions rises from 22.0°C to 30.5°C.
    Assuming that no heat is lost to the surroundings or to the container what is the heat of reaction for:
    $H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$ in units of kJ/mol of water formed.
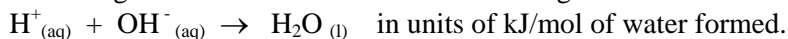
    [The heat capacity of water and these dilute aqueous solutions is about
    4.2 J °C^{-1} g^{-1} and the densities may be taken as 1.00 g/mL]

    A) 3.6   **B)** 13   **C)** 36   **D)** 71   **E)** 256

2. Which of the following is the strongest oxidizing agent?

    A) Na   **B)** I$^-$ **C)** I$_2$ **D)** F$^-$ **E)** F$_2$

3. Most households with a home water softener unit have a tap that bypasses the water softener. This is used for drinking water. This plumbing arrangement is recommended because the softened water:

    A) contains increased levels of sodium.
    B) contains too little chlorine to be sanitary.
    C) contains harmful particles of resin softening agent.
    D) has an unhealthy pH level.
    E) lacks nutritional amounts of calcium

4. The solubility of Cu(OH)$_{2 (s)}$ is 1.7 x 10^{-6} grams / 100 mL of solution at a certain temperature.
    The value of the solubility product at this temperature is:

    A) 2 x 10^{-23} **B)** 5 x 10^{-21} **C)** 2 x 10^{-20} **D)** 5 x 10^{-18} **E)** 5 x 10^{-15}

5. Which of the following list of molecules is non-polar?

    A) AsF$_3$ **B)** AsF$_5$ **C)** NH$_3$ **D)** OF$_2$ **E)** SO$_2$

Various tests are done on 0.10 M solutions of a series of chemicals contained in five flasks labeled as:
      A: NaCl   **B:** K_2SO_4 **C:** CH_3OH **D:** HCOOH   **E:** Li_3PO_4

6. Which of the above solutions shows the least electrical conductivity?

A) A   **B)** B   **C)** C   **D)** D   **E)** E

7. Which solution has the highest boiling point?

A) A   **B)** B   **C)** C   **D)** D   **E)** E

8. Which solution has the most basic pH?

A) A   **B)** B   **C)** C   **D)** D   **E)** E

9. How many unshared electron pairs are in a molecule of the amino acid glycine:
             H_2N-CH_2-COOH

A) Zero   **B)** Three   **C)** Four   **D)** Five   **E)** Six

10. Which of the following is amphoteric in aqueous solution?

A) HCO_3^- **B)** NO_3^- **C)** SO_4^{2-} **D)** OH^- **E)** CN^-

11. Natural copper is a mixture of only 2 isotopes. One isotope has 29 protons, 34 neutrons, and a relative abundance of 69.17%.
If the relative atomic mass of natural copper is 63.6, how many neutrons must there be in the second isotope?

A) 31   **B)** 32   **C)** 35   **D)** 36   **E)** 38

Technicium 99 is a radioactive element used in medical diagnostic testing. Typically, a patient is fed some food inoculated with the isotope in the compound sodium pertechnitate ($NaTcO_4$) and the progress of the isotope through the body is followed with a whole-body gamma ray spectrometer.
A typical dose for an imaging test is 10 milliCuries.
The radioactive half-life is about 6 hours.

12.   The element symbol for the primary decay product of this medical isotope is:

A) $^{96}_{41}Nb$ B) $^{99}_{42}Mo$ C) $^{99}_{43}Tc$ D) $^{99}_{44}Ru$ E) $^{103}_{45}Pd$

13.   24 h after ingestion of a dose of 10 mCu, about how much of the radioisotope will have decayed?

A) 0.63 mCu   B) 2.5 mCu   C) 7.5 mCu   D) 8.8 mCu   E) 9.4 mCu

14.   Technicium 99 is generated in medical laboratories by eluting the product from a column containing a radioactive isotope of Molybdenum.
The decay sequence inside the column is as follows:

$$^{99}_{42}Mo \longrightarrow {}^{99}_{43}Tc + X$$
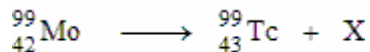
   where X represents one:

A) alpha particle   B) beta particle   C) gamma ray   D) positron   E) neutron

15.   Most antiperspirants use an active ingredient that contains salts of aluminum and of which other metal element?

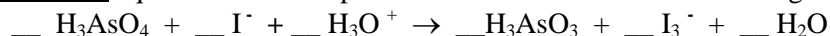A) Na   B) Sn   C) Zr   D) Zn   E) Cu

16. Soft drinks such as colas may contain several different acids.
The acid that is present in the highest concentration is:

A) Citric acid   D) Acetic acid
B) Ascorbic acid   E) Carbonic acid
C) Phosphoric acid

This <u>unbalanced</u> equation describes part of an "iodine clock" reaction using the toxic chemical, arsenic acid.

$$\_\_\ H_3AsO_4\ +\ \_\_\ I^-\ +\ \_\_\ H_3O^+\ \rightarrow\ \_\_H_3AsO_3\ +\ \_\_\ I_3^-\ +\ \_\_\ H_2O$$

The reaction rate law for this equation is:
$$Rate = k\ [H_3AsO_4]\ [\ I^-\ ]\ [H_3O^+]$$

17. When the above equation is balanced by inserting the correct coefficients in the blanks, what is the ratio of I^- ions to H_3O^+ ions?

A) 1 : 1 **B)** 1.5 : 1 **C)** 2 : 1 **D)** 2.5 : 1 **E)** 3 : 1

18. What is the order of the reaction rate with respect to I^- ions?

A) 1 **B)** 2 **C)** 3 **D)** 4 **E)** 5

19. Some people try to avoid antiperspirants that contain aluminum by using "natural" products. One antiperspirant is labeled as a "natural crystal". In fact, this crystal is Alum. The formula for the material is $Al_2(SO_4)_3 \cdot 18\ H_2O$
In a 200 g stick, about how much of the crystal's mass is water?

A) 18 g **B)** 64 g **C)** 68 g **D)** 100 g **E)** 132 g

20. Which pure compound has the highest vapor pressure under normal room conditions?

A) CH_3-OH
B) CH_3CH_2-OH
C) CH_3-O-CH_3
D) HO-CH_2-CH_2-OH
E) CH_3CHO

21. In many schools, water fountains are set open to run for 30 minutes or so after each weekend or holiday. The main reason that water is left running, is to remove:

A) dissolved copper
B) dissolved iron
C) dissolved lead
D) excess sodium
E) warm water that tastes "flat"

22. A portion of the phase diagram for a certain pure substance is shown below.
The Triple Point occurs at 550 kPa and **-20°C**.
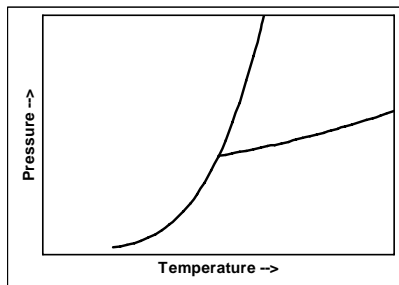
What is the first transition that occurs when the material is heated from -40°C to +40°C at a constant pressure of 500 kPa?

A) boiling   **D)** fusion

B) melting   **E)** sublimation

C) condensation

23. When measured at 25°C, natural "clean" rain has a pH of 5.5 due to dissolved CO_2 gas from the atmosphere. This corresponds to which concentration of hydronium ions?

$$[K_w = 1 \times 10^{-14} \text{ at } 25°C]$$

A) 5.0×10^{-5} mol L^{-1}

B) 3.2×10^{-6} mol L^{-1}

C) 3.2×10^{-9} mol L^{-1}

D) 2.0×10^{-10} mol L^{-1}

E) Unknown. pH does not measure hydronium ions.

24. If one molecule within a virus has a mass of about 1×10^{-18} g , approximately how many atoms are in the molecule? (Choose the nearest estimate.)

A) 10^2 **B)** 10^5 **C)** 10^8 **D)** 10^{11} **E)** 10^{14}

25. Which gas contributes most to the atmospheric greenhouse effect?

A) Water Vapor   **D)** Sulfur dioxide

B) Methane   **E)** Carbon dioxide

C) Ozone

26. The chemical preservative Thimerosol is used to preserve vaccines and other injectable solutions. It has caused recent controversy in the media because it contains which element?

A) Silver   **B)** Arsenic   **C)** Lead   **D)** Fluorine   **E)** Mercury

27. Phenolphthalein is commonly used as an acid-base indicator dye. In basic solution, the color of light most strongly absorbed by the dye is:
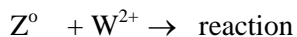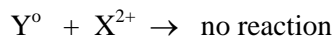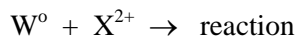
A) red
B) green
C) blue

D) red & blue equally
E) None. The solution is colorless.

28. In which case below has the hydrogen ion concentration increased by one hundred times its initial value?

Case	Initial pH	Final pH
A	7.0	9.0
B	6.7	3.7
C	5.9	1.3
D	4.5	2.5
E	1.1	3.1

A) A　　　　**B)** B　　　　**C)** C　　　　**D)** D　　　　**E)** E

29. The information below was collected from an experiment testing the relative reactivity of metals. Metals are immersed in a solution of another metal ion.

$$W^{o} + X^{2+} \rightarrow \text{reaction}$$
$$Y^{o} + X^{2+} \rightarrow \text{no reaction}$$
$$Z^{o} + W^{2+} \rightarrow \text{reaction}$$

Which of the following lists shows the metals in order of <u>increasing</u> tendency to be oxidized?

A) W, X, Y, Z
B) X, Y, Z, W
C) Z, W, X, Y

D) Y, X, W, Z
E) Z, W, Y, X

30. The acid in most car lead-acid batteries has the traditional name "Oil of Vitriol"
The formula for this acid is:

A) CH_3COOH　　**B)** HNO_3　　**C)** HCl　　**D)** H_2SO_4　　**E)** H_3PO_4

31. A compound known to be formed from phosphorus and sulfur is analyzed as 44% sulfur by mass. Which of the following simplest formulas corresponds to this analysis?

A) PS　　**B)** P_2S_3　　**C)** P_4S_3　　**D)** P_4S_5　　**E)** P_4S_7

32. What compound is mainly responsible for the brown color of photochemical smog?

A) NO_2　　**B)** NO　　**C)** N_2O_4　　**D)** SO_2　　**E)** O_3

33. During a power failure, a paraffin candle ($C_{25}H_{52}$) was used to provide light for 2 hours. The average rate of combustion of the paraffin was 1.57×10^{-3} mol / minute.
If the initial mass of the candle was 100.0 g, what was the mass of the candle after 2 h of burning?

A) 34 g   **B)** 42 g   **C)** 55 g   **D)** 58 g   **E)** 66 g

34. A simple chemical test for SO_2 gas is to pass the gas over a piece of filter paper soaked in $Na_2Cr_2O_7$ solution. The fact that the color of the paper goes from orange to green indicates that sulfur dioxide:

A) forms an acidic solution   **D)** acts as an oxidizing agent
B) acts as a reducing agent   **E)** none of the above
C) forms a basic solution

35. In 1964, Cole and Eaton accomplished the synthesis of the novel hydrocarbon "Cubane"... a cubic molecule bonded entirely with single bonds.
What is the formula of Cubane?

A) C_4H_8 **B)** C_6H_6 **C)** C_6H_{12} **D)** C_8H_8 **E)** C_8H_{18}

36. The following reaction occurs when a 0.20M solution of $Sn(NO_3)_2$ is titrated with a 0.10M solution of $KMnO_4$.
$$2MnO_4^- + 5\,Sn^{2+} + 16\,H^+ \rightarrow 2\,Mn^{2+} + 5\,Sn^{4+} + 8\,H_2O$$

What volume of the $KMnO_4$ solution is required to reach the equivalence point when added to 25.0 mL of an acidified Sn^{2+} solution?

A) 10.0 mL   **B)** 20.0 mL   **C)** 25.0 mL   **D)** 50.0 mL   **E)** 66.7 mL

37. The Bombardier beetle uses an explosive discharge as a defensive measure. The beetle mixes hydrogen peroxide and hydroquinone in a special chamber. The heat produced boils water and causes the solution to squirt out of the chamber at the attacker.
The overall reaction is:
$$C_6H_4(OH)_{2\,(aq)} + H_2O_{2\,(aq)} \rightarrow C_6H_4O_{2\,(aq)} + 2\,H_2O_{(g)}$$
       (hydroquinone)   (quinone)
According to the data in the following table, what is the ΔH for this reaction in units of kJ/mol of hydroquinone?
$$C_6H_4(OH)_{2\,(aq)} \rightarrow C_6H_4O_{2\,(aq)} + H_2 \qquad \Delta H = +177.4 \text{ kJ}$$
$$H_{2\,(g)} + O_{2\,(g)} \rightarrow H_2O_{2\,(aq)} \qquad \Delta H = -191.2 \text{ kJ}$$
$$H_{2\,(g)} + \tfrac{1}{2}O_{2\,(g)} \rightarrow H_2O_{(g)} \qquad \Delta H = -241.8 \text{ kJ}$$

A) +126   **B)** -13.8   **C)** -115   **D)** -387   **E)** -610

38. Which of the following scientists is NOT generally recognized as a significant contributor to the development of the quantum mechanical model of the atom?

A) Max Planck   **D)** Erwin Schrödinger
B) Albert Einstein   **E)** Louis de Broglie
C) Ernest Rutherford

39. According to the Bohr model of the atom, when a photon of light is released from an atom,

    A) the atom has returned to its ground state.
    B) an electron has been converted into light energy.
    C) the energy of the atom has increased by one quantum.
    D) an electron has dropped from a high energy orbit to one of lower energy.
    E) the atom has become ionized.

40. In the synthesis of the ester butyl acetate, 1.8 mol of 1-butanol ($C_4H_{10}O$) was mixed with 1.2 mol of acetic acid ($C_2H_4O_2$) and 0.8 mol of 1-butyl acetate ($C_6H_{12}O_2$) was produced. The percentage yield of the product was:

    A) 75%   **B)** 66%   **C)** 59%   **D)** 44%   **E)** 29%

This information refers to the following two questions [# 41 and # 42].

Data for the graph below were recorded by adding 0.1 M NaOH to a 0.1M sample of a weak monoprotic acid (HX).

Titration curve
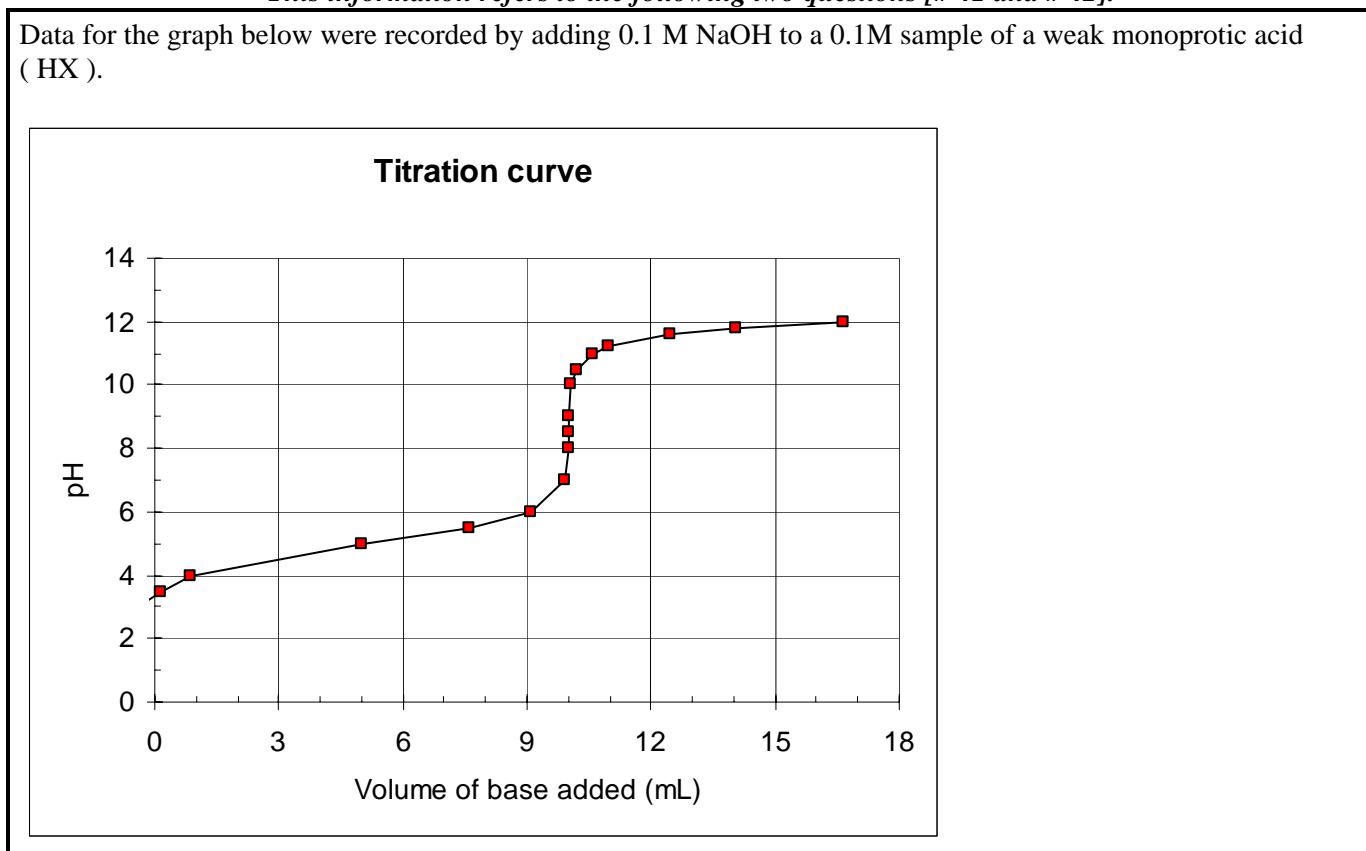
41. The approximate K_a of this weak acid is:

    A) 1×10^{-5} **B)** 1×10^{-6} **C)** 1×10^{-7} **D)** 1×10^{-10} **E)** 1×10^{-12}

42. The best indicator dye to show the endpoint of this titration would be:

    A) methyl orange   **D)** bromthymol blue
    B) phenolphthalein   **E)** fluorescein
    C) congo red

43. The ground state electron configuration of an atom is: $[Ne]\ 3s^2\ 3p^4$.
The symbol that represents this atom correctly is:

A) Mg   **B)** Si   **C)** As^{1+} **D)** P^{3-} **E)** S

44. 4.0 moles of pure $N_2O_{4\ (g)}$ are placed in a sealed container and allowed to come to equilibrium at constant temperature. By monitoring the color change, it is determined that 50% of the $N_2O_{4\ (g)}$ has dissociated into $NO_{2\ (g)}$. The value of K_p at this temperature is:

A) 1/4   **B)** 1   **C)** 2   **D)** 4   **E)** 8

This question was eliminated.

45. A Lewis Dot Diagram for the valence electrons of an atom with a configuration of $1s^2\ 2s^2\ 2p^3$ would show:

A) 1 electron pair and 3 unpaired electrons   **D)** 2 electron pairs and 3 unpaired electrons
B) 2 electron pairs and 1 unpaired electron   **E)** 1 electron pairs and 5 unpaired electron
C) 3 electron pairs and 1 unpaired electron

46. For a given chemical equilibrium system it is found that the equilibrium constant K_c gets smaller as the temperature decreases.
In order for this to occur, which of the following statements are TRUE?
         1. The forward reaction must be endothermic.
         2. The forward reaction is favored.
         3. The equilibrium concentration of reactants increases.
         4. A catalyst must have been added.

A) 1 & 2   **B)** 1 & 3   **C)** 2 & 3   **D)** 2 & 4   **E)** 3 & 4

47. A variety of popcorn contains 10% moisture.
         10 average kernels show a mass of 1.67 g
         10 average kernels displace 1.25 mL of water
If the kernels do not explode until all of the moisture is changed to vapor, what is the maximum pressure that could develop inside the kernel? (Assume uniform heating throughout the kernel.)

A) 230 kPa   **B)** 414 kPa   **C)** 6 MPa   **D)** 23 MPa   **E)** 414 MPa

48. The following Kinetic Energy Distribution Diagram shows the threshold energies of two reactions labeled X and Y
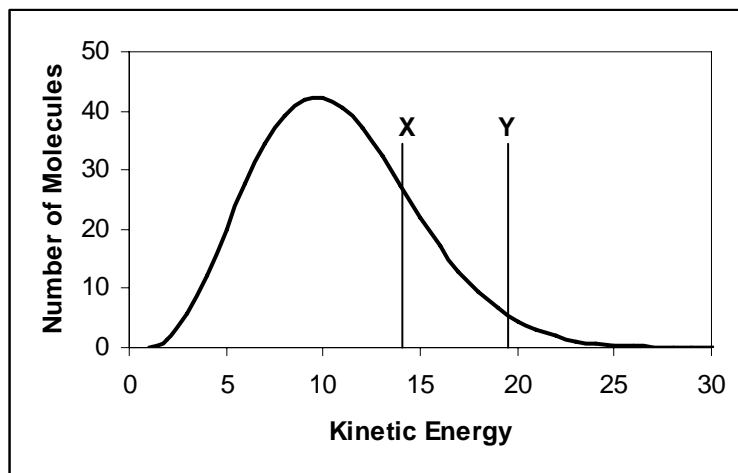

Which of the following statements are TRUE about these reactions?
      1. Reaction X has a lower energy of activation than reaction Y.
      2. A greater number of molecules exceed the threshold energy for reaction X than
         for reaction Y
      3. Reaction X has a larger ΔH than reaction Y
      4. A small increase in temperature is more likely to double the rate of reaction X
         than for reaction Y.

A) 1 & 2   **B)** 1 & 4   **C)** 2 & 3   **D)** 2 & 4   **E)** 3 & 4

49. An acetylene welding torch has a steel cylinder containing acetylene and a steel cylinder containing oxygen each connected to the torch through hoses. The gases mix in the torch and combust to make a flame hot enough to melt iron.
      Acetylene reacts with oxygen according to the following equation:
$$2\,C_2H_{2\,(g)} + 5\,O_{2\,(g)} \rightarrow 4\,CO_{2\,(g)} + 2\,H_2O_{(g)}$$
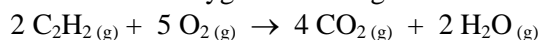
When a 16.5 L cylinder of compressed oxygen was used by a welder, the pressure in the cylinder changed from 1.050 MPa to 1.010 MPa. The temperature of both cylinders was a constant 22^oC.
What mass of acetylene was combusted from the other cylinder?

A) 2.8 g   **B)** 7.0 g   **C)** 37 g   **D)** 70 g   **E)** 93 g

50. The pH of milk is normally 6.5

As certain natural bacteria metabolize lactose sugar in the milk they produce lactic acid. The increase in lactic acid results in a lower pH. When the pH reaches about 5.0, casein protein micelles lose their negative charge and clump together. These visible clumps indicate that the milk has "gone sour" and may be unfit to drink.

Lactic acid (2-hydroxypropanoic acid) is a monoprotic acid which can be represented for convenience by the symbol HLac.
The $K_a = 7.9 \times 10^{-5}$ for the equilibrium:

$$HLac_{(aq)} \Leftrightarrow H^+_{(aq)} + Lac^-_{(aq)}$$
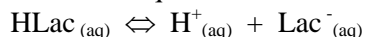
By what factor does the concentration ratio [HLac] : [Lac⁻] change when fresh milk turns to sour milk?

A) 0.06 **B)** 1.3 **C)** 8 **D)** 16 **E)** 32

51. The graph below shows the variation of K_w with temperature for the equilibrium:

$$H_2O_{(l)} \Leftrightarrow H^+_{(aq)} + OH^-_{(aq)}$$
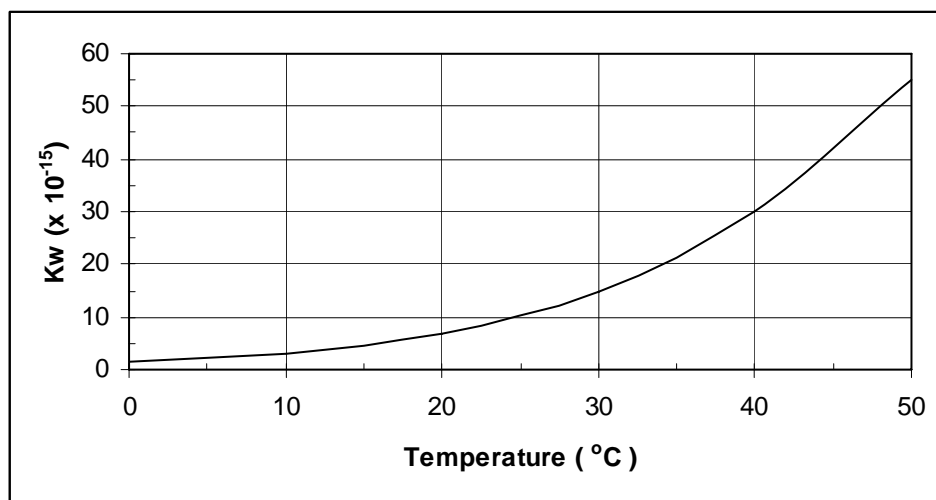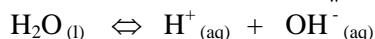
From this information, what is the pH of pure water at body temperature?

A) 6.6 **B)** 6.7 **C)** 6.8 **D)** 7.0 **E)** 7.2

52. Stalactites grow very slowly in caves, as water containing bicarbonates of calcium and magnesium, releases CO_2 in reactions such as:

$$Ca^{2+}_{(aq)} + 2\,HCO_3^-_{(aq)} \Leftrightarrow CO_{2(g)} + H_2O + CaCO_{3(s)}$$
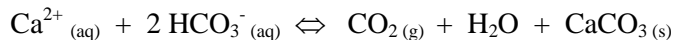
If a colony of bats is successful in overwintering in an area of a cave, their respiration will significantly increase the CO_2 levels in the air. In response to this change in conditions, the stalactites would tend to:

A) grow faster **D)** shrink in size
B) grow at the same rate **E)** have wider growth rings
C) remain the same size

53. A voltaic cell is prepared by placing a Magnesium metal electrode in a beaker of 1.0 mol/L magnesium nitrate ($Mg(NO_3)_2$) solution. The beaker is connected by a salt bridge to a beaker containing a silver electrode in a 1.0 mol/L silver nitrate ($AgNO_3$) solution. The electrodes are connected by wire to a voltmeter.
The spontaneous cell reaction is:

$$Mg_{(s)} + 2\,Ag^+_{(aq)} \rightarrow Mg^{2+}_{(aq)} + 2Ag^o_{(s)}$$
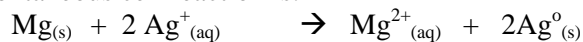
If a 2.5 mol/L solution of sodium chloride (NaCl) is added to the beaker containing silver nitrate,

A) the reading on the voltmeter will decrease.
B) the reading on the voltmeter will increase.
C) the concentration of magnesium ions will increase.
D) crystals of sodium nitrate will form around the electrode.
E) chlorine gas (Cl_2) will form at the cathode.

54. A voltaic cell involves the following half-reactions:

$$Ag^+_{(aq)} + e^- \rightarrow Ag^o_{(s)} \qquad\qquad E^o = +0.80\ V$$
$$Ni^{2+}_{(aq)} + 2e^- \rightarrow Ni^o_{(s)} \qquad\qquad E^o = -0.25\ V$$

The electrodes are connected by a wire and electricity flows through the wire until the mass of the nickel electrode has changed by 17.7 g. The mass of the silver electrode will have changed by

A) 1.58 g   **B)** 8.85 g   **C)** 17.7 g   **D)** 35.4 g   **E)** 64.8 g

55. Acid-base indicator dyes are chemicals which
A) have positive and negative ions of different colors.
B) change color when the pH of a solution is 7
C) are red in acid and blue in base.
D) change color when the pH of a solution changes over a specific range
E) are used to detect an excess of positive or negative ions in a solution

End of Test

Answer Section

1. D
2. E
3. A
4. C
5. B
6. C
7. E
8. E
9. D
10. A
11. D
12. C
13. E
14. B
15. C
16. E
17. B
18. A
19. D
20. C
21. C
22. E
23. B
24. B
25. A
26. E
27. B
28. D
29. D
30. D

31. C
32. A
33. A
34. B
35. D
36. B
37. C
38. C
39. D
40. B
41. A
42. B
43. E
44. ~~E~~ **eliminated**
45. A
46. B
47. D
48. A
49. A
50. E
51. C
52. D
53. A
54. E
55. D