



**The 58<sup>th</sup> Annual  
Merck State Science Day Competition  
May 20, 2008  
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 **50 items** that will be scored. 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, here are several subject-specific items below that you may find useful in answering certain questions. Be sure to read them.

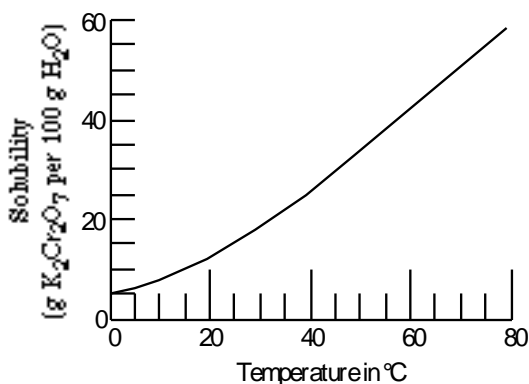
**INFORMATION THAT MAY BE USEFUL IN SOLVING THE PROBLEMS**

<b>Universal gas constant:</b>	<b>R = 0.0821 atm-liter/(mole-K)</b>	<b>1dm<sup>3</sup> = 1 L</b>
	<b>R = 8.31 kPa-liter/(mole-K)</b>	<b>PV=nRT</b>
<b>Specific heat H<sub>2</sub>O = 4.18 J/g°C</b>		
<b>1 Faraday (F) = 96,500 coulombs/mole</b>		<b>1 calorie = 4.184 joules</b>
<b>= 96,500 joules/volt</b>		<b>Q = mcΔT</b>
<b>1 electron volt/atom = 96.5 kilojoules/mole</b>		<b>KE<sub>ave</sub> = ½mv<sup>2</sup></b>

## Multiple Choice

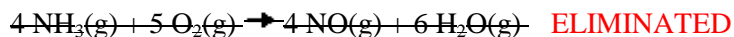
Identify the choice that best completes the statement or answers the question.

- 1) A mixture of 100 g of  $K_2Cr_2O_7$  and 200 g of water is stirred at  $60\text{ }^\circ\text{C}$  until no more of this salt dissolves. The resulting solution is decanted (poured off) and cooled to  $20\text{ }^\circ\text{C}$ . What mass of  $K_2Cr_2O_7$  crystallizes from the solution during the cooling?



- A) 24 g      B) 31 g      C) 43 g      D) 62 g      E) 86 g
- 2) When rain containing sulphurous acid falls into lakes containing dissolved calcium carbonate, the pH of the lake drops slightly and then remains relatively constant. Which of the following statements best describes a change that occurs in the lake water?
- A) Carbonic acid is formed.  
 B) The calcium sulphite formed neutralizes the sulphurous acid.  
 C) The carbonate ion decomposes into carbon dioxide and water.  
 D) The formation of bicarbonate ion,  $HCO_3^-(aq)$ , creates a buffer system with carbonate ion,  $CO_3^{2-}(aq)$ .
- 3) The chemical reaction in which a single species is both oxidized and reduced is called disproportionation. Which of the following is an example of this type of reaction?
- A)  $2Na(s) + I_2(s) \rightarrow 2NaI(s)$   
 B)  $2F_2(g) + O_2(g) \rightarrow 2OF_2(g)$   
 C)  $Cl_2(aq) + H_2O(l) \rightarrow HOCl(aq) + H^+(aq) + Cl^-(aq)$   
 D)  $2NH_3(aq) + NaOCl(aq) \rightarrow N_2H_4(aq) + NaCl(aq) + H_2O(l)$
- 4) What will be the effect of adding some solid  $AgNO_3$  to a saturated solution of  $AgCl$ ?
- A) The  $AgNO_3$  will not dissolve.  
 B) More solid  $AgCl$  will dissolve.  
 C) More solid  $AgCl$  will be produced.  
 D) The  $AgNO_3$  will not affect the  $AgCl$  equilibrium

5) Which equation describes the relationship between the rates at which  $O_2$  is consumed and NO is produced?



- A)  ~~$-\frac{\Delta(O_2)}{\Delta t} = \frac{\Delta(NO)}{\Delta t}$~~
- B)  ~~$-4 \frac{\Delta(O_2)}{\Delta t} = 5 \frac{\Delta(NO)}{\Delta t}$~~
- C)  ~~$-5 \frac{\Delta(O_2)}{\Delta t} = 4 \frac{\Delta(NO)}{\Delta t}$~~
- D)  ~~$-\frac{1}{5} \frac{\Delta(O_2)}{\Delta t} = \frac{1}{4} \frac{\Delta(NO)}{\Delta t}$~~
- E)  ~~$-\frac{1}{4} \frac{\Delta(O_2)}{\Delta t} = \frac{1}{5} \frac{\Delta(NO)}{\Delta t}$~~

6) A mixture of  $BaCl_2$  and  $Ba(NO_3)_2$ , with a total mass of 4.00 g, is dissolved in water. Silver nitrate solution,  $AgNO_3(aq)$ , is added, and all of the dissolved  $Cl^-$  is precipitated as  $AgCl$ . The mass of the precipitate is 1.376 g. What is the percentage (by mass) of  $BaCl_2$  original sample?

- A) 25.0%
- B) 34.4%
- C) 50.0%
- D) 66.6%
- E) 75%

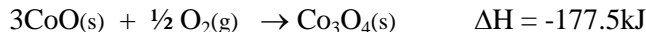
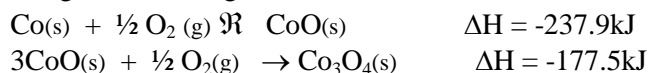
7) A sample of methane gas,  $CH_4$ , effused through a pinhole in 4.2 s. How long will it take for the same amount of  $N_2$  to effuse through the pinhole under the same conditions?

- A) 3.1 s
- B) 4.2 s
- C) 5.5 s
- D) 7.3 s
- E) 9.6 s

8) Calculate the enthalpy change,  $\Delta H$ , for the reaction



using the following information:



- A) 60.4 kJ
- B) 415.4 kJ
- C) 536.2 kJ
- D) 891.2 kJ
- E) -536.2 kJ

9) When 72.0 g of a nonvolatile molecular solid was dissolved in 200. g water, the solution began to freeze at  $-3.72^\circ C$ . What is the molar mass of the solute?

- A) 28.8 g/mol
- B) 36.0 g/mol
- C) 49.3 g/mol
- D) 180 g/mol
- E) 360 g/mol

10) Which of the following molecules is polar?



- A) only  $CCl_3Br$
- B) only  $NF_3$
- C) only  $GeBr_2$
- D) both  $BF_3$  and  $NF_3$
- E) all of  $CCl_3Br$ ,  $GeBr_2$ ,  $NF_3$

11) Which of the following substances has the lowest melting point?

- A) Na<sub>2</sub>O      B) MgO      C) Al<sub>2</sub>O<sub>3</sub>      D) SiO<sub>2</sub>      E) P<sub>4</sub>O<sub>10</sub>

- 12) Which one of the following does not describes a decrease in order of size of atomic and/or ionic radius?  
 A) Li > Be > B  
 B) Cl > Ar > K  
 C) Cl<sup>-</sup> > Ar > K<sup>+</sup>  
 D) Na<sup>+</sup> > Mg<sup>2+</sup> > Al<sup>3+</sup>  
 E) P<sup>3-</sup> > S<sup>2-</sup> > Cl<sup>-</sup>
- 13) In a sewage plant the pH of waste water is adjusted to reduce biological activity. If 0.37 g of solid Ca(OH)<sub>2</sub> are added to each liter of water (at pH 7.0) coming into the plant, then, assuming that the temperature remains at 25°C throughout, the pH of the water will become approximately:  
 A) 2.0  
 B) 2.3  
 C) 8.0  
 D) 11.7  
 E) 12.0
- 14) Some standard bond enthalpy terms (in kJ/mol) are:

$$\begin{aligned} \langle D \rangle(\text{C-H}) &= 413, \langle D \rangle(\text{C-O}) = 358, \langle D \rangle(\text{C=O}) = 805, \\ \langle D \rangle(\text{O=O}) &= 498, \text{ and } \langle D \rangle(\text{O-H}) = 464. \end{aligned}$$

Using these values the standard molar enthalpy change of combustion of methanol,  $\Delta H_{\text{combustion}}(\text{CH}_3\text{OH})$ , can be estimated to be:

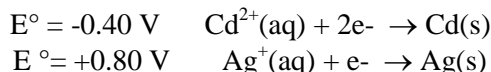
- A) - 245 kJ/mol  
 B) - 409 kJ/mol  
 C) - 658 kJ/mol  
 D) - 689 kJ/mol  
 E) - 726 kJ/mol
- 15) Consider the following indicator equilibrium:
- $$\begin{array}{ccccccc} \text{HIn (aq)} & + & \text{H}_2\text{O (l)} & \leftrightarrow & \text{H}_3\text{O}^+ \text{ (aq)} & + & \text{In}^- \text{ (aq)} \\ \text{colorless} & & & & & & \text{blue} \end{array}$$
- What is the effect of adding HCl to a blue sample of this indicator?  
 A) Equilibrium shifts left; less blue  
 B) Equilibrium shifts left; more blue  
 C) Equilibrium shifts right; less blue  
 D) Equilibrium shifts right; more blue  
 E) no change
- 16) In 5.0 years, <sup>60</sup>Co loses one-half of its radioactivity. What percentage of the original radioactivity would remain at the end of 20 years?  
 A) 0%      B) 0.16%      C) 6.25%      D) 12.5%      E) 25%

- 17) The molecule  $\text{:}\ddot{\text{O}}=\text{C}=\ddot{\text{N}}-\text{H}$  has been detected in gas clouds between stars. The predicted C—N—H bond angle is about  
 A) 60°      B) 90°      C) 109°      D) 120°      E) 180°

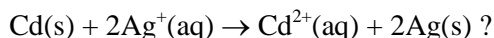
- 18) The hybridization that accounts for the electron arrangement of xenon tetrafluoride?

- A)  $sp$                       B)  $sp^2$                       C)  $sp^3$                       D)  $sp^3 d$                       E)  $sp^3 d^2$

19) Given these standard reduction potentials:



What is  $E^\circ$  for



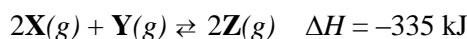
- A) 0.00 V  
 B) +0.20 V  
 C) +0.40 V  
 D) +1.20 V  
 E) +1.60 V
- 20) Three liters of 0.20 M  $\text{Na}_2\text{SO}_4(\text{aq})$  and one liter of 0.40 M  $\text{NaNO}_3(\text{aq})$  are mixed. The resulting concentrations of  $\text{Na}^+$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  are, respectively:  
 A) 0.20 mol/L, 0.40 mol/L, 0.20 mol/L  
 B) 0.25 mol/L, 0.20 mol/L, 0.15 mol/L  
 C) 0.30 mol/L, 0.10 mol/L, 0.15 mol/L  
 D) 0.40 mol/L, 0.15 mol/L, 0.10 mol/L  
 E) 0.40 mol/L, 0.10 mol/L, 0.15 mol/L
- 21) The greatest difference between the first and second ionization energies would be exhibited by atoms of  
 A) Neon  
 B) Silicon  
 C) Sodium  
 D) Aluminum  
 E) Magnesium
- 22) The stable isotope of fluorine is F. The nuclear charge of the fluoride ion,  $\text{F}^-$ , is  
 A) 1+  
 B) 7+  
 C) 9+  
 D) 1-  
 E) 10+
- 23) In what respect does an atom of magnesium differ from a magnesium ion ( $\text{Mg}^{2+}$ )?  
 A) The ion has two more protons than the atom. **ELIMINATED**  
 B) The ion will react more readily with free  $\text{Cl}_2$ .  
 C) The ion has two more planetary electrons than the atom  
 D) The ion has a more stable electronic arrangement than the atom.  
 E) The positive charge on the nucleus of the ion is two units greater than the nuclear charge on the atom.
- 24) The ground state electron distribution for the  $\text{Sn}^{2+}$  ion is  
 A)  $[\text{Kr}]4d^{10}5s^15p^1$   
 B)  $[\text{Kr}]4d^{10}5s^2$   
 C)  $[\text{Kr}]4d^{10}5s^25p^2$   
 D)  $[\text{Kr}]4d^{10}5p^2$   
 E)  $[\text{Kr}]4d^{10}5p^26s^2$
- 25) The elements in an ionic compound are held together by  
 A) electrostatic forces of attraction.

- B) the formation of hybrid orbitals.  
 C) the spin of paired electrons.  
 D) van der Waals forces.  
 E) an electron pair.
- 26) Which characteristic is generally true of nonmetallic oxides?  
 A) They are in general ionic compounds.  
 B) They react with water to form bases.  
 C) They are in general covalent compounds.  
 D) They react with acids to form a salt and water.  
 E) They cannot be prepared directly from the elements.
- 27) According to modern bonding theory the number of sigma ( $\sigma$ ) and pi ( $\pi$ ) bonds in the ethylene molecule  $\text{H}_2\text{C}=\text{CH}_2$  is  
 A) 1  $\sigma$  and 4  $\pi$   
 B) 1  $\sigma$  and 5  $\pi$   
 C) 1  $\pi$  and 4  $\sigma$   
 D) 1  $\pi$  and 5  $\sigma$   
 E) 2  $\pi$  and 4  $\sigma$
- 28) When one molecule of  $\text{Ag}(\text{NH}_3)_2\text{Cl}$  dissociates, the number of ions formed is  
 A) 1                      B) 2                      C) 3                      D) 4
- 29) Five metals are represented by the symbols **Q**, **R**, **S**, **T**, and **U**. When a solution containing all five ions at 1 M concentration is electrolyzed with a small applied voltage, which metal is most likely to be deposited first on the cathode?

Standard Reduction Potentials	Unknown Metals $E^0$
<b>Q</b> $\rightleftharpoons \text{Q}^{2+} + 2e^-$	0.76 V
<b>R</b> $\rightleftharpoons \text{R}^{2+} + 2e^-$	0.44 V
<b>S</b> $\rightleftharpoons \text{S}^{2+} + 2e^-$	0.13 V
<b>T</b> $\rightleftharpoons \text{T}^{3+} + 3e^-$	-0.34 V
<b>U</b> $\rightleftharpoons \text{U}^+ + e^-$	-0.80 V

- A) Q                      B) R                      C) S                      D) T                      E) U
- 30) Household water softening systems are popular in many regions of the country to reduce the effects of hard water. When soap forms scum in hard water it is because  
 A) soap and hard water repel each other.  
 B) soap does not hydrolyze in hard water.  
 C) soap requires an acid solution while hard water is alkaline.  
 D) soap forms a precipitate with the metallic ions in the water.  
 E) soap removes the dirt in the hard water in the form of curds.

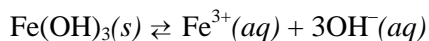
- 31) For the reaction:



Which combination of pressure and temperature gives the highest yield of **Z** at equilibrium?

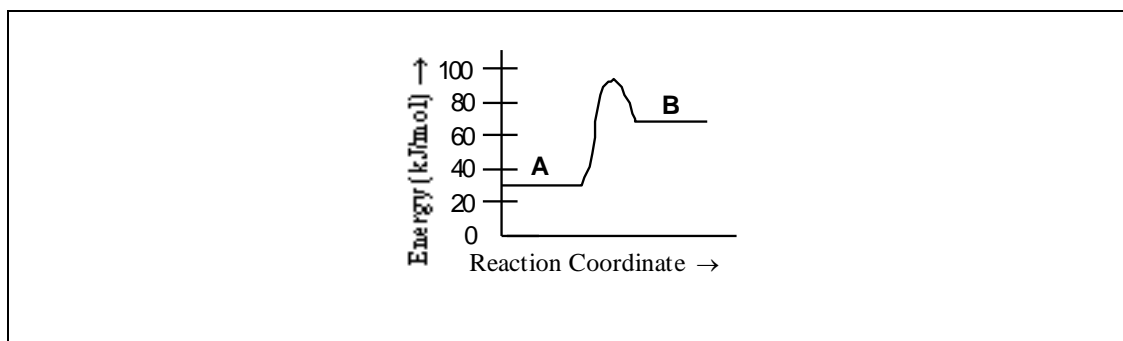
- A) 1000 atm and 500 °C
- B) 500 atm and 500 °C
- C) 1000 atm and 100 °C
- D) 500 atm and 100 °C
- E) catalyst, 500 atm and 100 °C

32) Which is the solubility product constant expression,  $K_{sp}$ , for iron(III) hydroxide,  $\text{Fe}(\text{OH})_3(s)$ ?

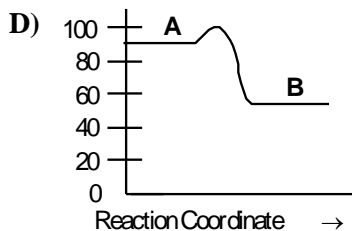
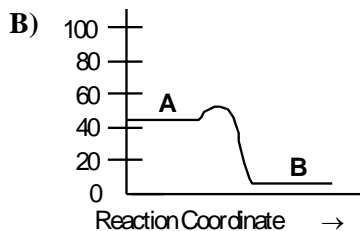
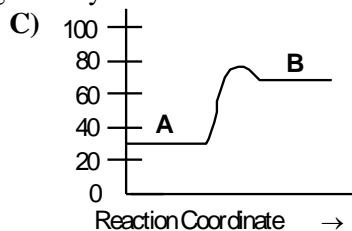
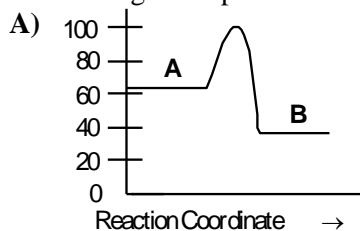


- A)  $K_{sp} = [\text{Fe}^{3+}] [\text{OH}^{-}]^3$
- B)  $K_{sp} = \frac{[\text{Fe}^{3+}] [\text{OH}^{-}]^3}{[\text{Fe}(\text{OH})_3]}$
- C)  $K_{sp} = [\text{Fe}^{3+}] [3\text{OH}^{-}]^3$
- D)  $K_{sp} = [\text{Fe}^{3+}] [(\text{OH})_3^{-}]$

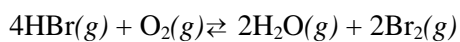
33) Consider the energy diagram for the reaction  $\text{A} \rightarrow \text{B}$

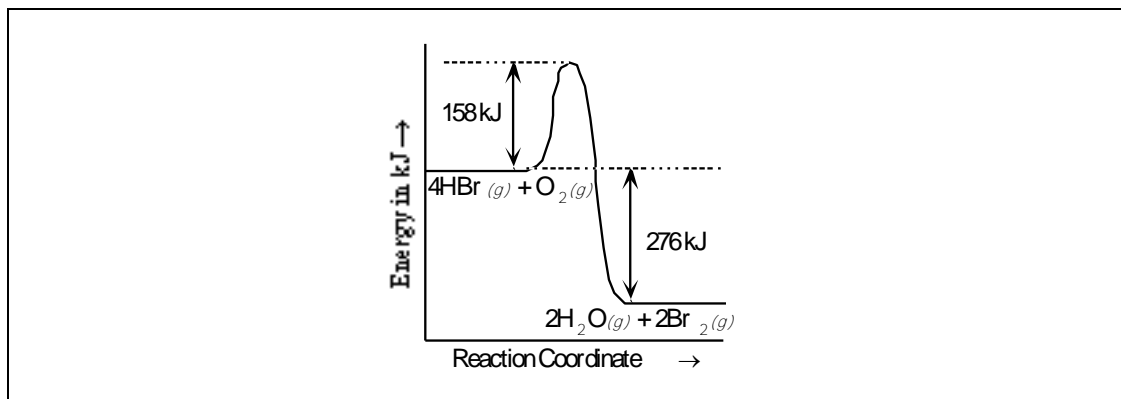


Which diagram represents reaction  $\text{A} \rightarrow \text{B}$  using a catalyst?



34) Consider this reaction at 500 °C:





What is the activation energy for the *reverse* reaction?

- A) 118 kJ      B) 158 kJ      C) 276 kJ      D) 434 kJ

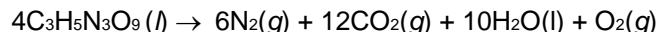
- 35) Sodium hydroxide, NaOH, is gradually added to a  $3.5 \times 10^{-4}$  M CoSO<sub>4</sub> solution. At what pH will cobalt hydroxide begin to precipitate?

$$K_{sp} = 2.5 \times 10^{-16} \text{ for Co(OH)}_2$$

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

- A) 9.53      B) 7.93      C) 6.07      D) 4.47      E) 1.85

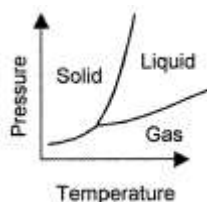
- 36) Under highly controlled conditions, the decomposition of nitroglycerin, C<sub>3</sub>H<sub>5</sub>N<sub>3</sub>O<sub>9</sub>, is used for the demolition of high rise buildings. The chemical equation for the reaction is:



What volume of gas is produced by the complete decomposition of 0.200 kg C<sub>3</sub>H<sub>5</sub>N<sub>3</sub>O<sub>9</sub>, assuming the gas is collected at 25°C and 101 kPa?

- A) 22 L      B) 102 L      C) 119 L      D) 172 L      E) 215 L

- 37) The phase diagram for a pure substance is shown in the diagram. The triple point is 517 kPa and -57°C. If the temperature is raised from -150°C to -50°C and the pressure remains constant at 400 kPa, what phase transition does the substance undergo?



- A) fusion  
B) vaporization  
C) sublimation  
D) condensation  
E) melting

- 38) Consider ice in equilibrium with liquid water at 273 K. Which of the following relationships is correct for  $G(s)$ , the free energy per mole of ice and  $G(l)$ , the free energy per mole of the liquid?

- A)  $G(s)$  is less than  $G(l)$   
B)  $G(s)$  is greater than  $G(l)$



- C)  $G(s)$  equals 0,  $G(l)$  equals 0  
 D)  $G(s)$  equals  $G(l)$ ; neither equals 0

- 39) A 10.0 g sample of silver is heated to 100.0 °C and then added to 20.0 g of water at 23.0 °C in a calorimeter. When thermal equilibrium was achieved, the temperature of the system was 25.0 °C. What is the specific heat of silver?  
 A) 0.11 J/g·°C  
 B) 0.22 J/g·°C  
 C) 3.4 J/gg·°C  
 D) 17 J/g·°C  
 E) 34 J/g·°C

- 40) Silver nitrate solution reacts with calcium chloride solution according to the equation. What mass of AgCl would be formed by mixing together a solution containing 12.6 g of AgNO<sub>3</sub> and 8.40 g of CaCl<sub>2</sub>?  
 A) 11.8 g      B) 11.2 g      C) 10.6 g      D) 9.8 g      E) 9.2 g

- 41) A student reacted a calcium carbonate boiling stone with a known concentration of hydrochloric acid. What volume, in mL, of 0.358 M HCl reacted with 0.250 g of the CaCO<sub>3</sub> boiling stone?



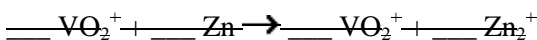
- A) 3.35 mL  
 B) 6.98 mL  
 C) 8.25 mL  
 D) 14.0 mL  
 E) 16.8 mL
- 42) In the following reaction, which substances are bases according to the Brønsted–Lowry definition?  

$$\text{HC}_2\text{H}_3\text{O}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{C}_2\text{H}_3\text{O}_2^-$$

- A) HC<sub>2</sub>H<sub>3</sub>O<sub>2</sub> and H<sub>2</sub>O  
 B) HC<sub>2</sub>H<sub>3</sub>O<sub>2</sub> and C<sub>2</sub>H<sub>3</sub>O<sub>2</sub><sup>-</sup>  
 C) H<sub>2</sub>O and C<sub>2</sub>H<sub>3</sub>O<sub>2</sub><sup>-</sup>  
 D) H<sub>3</sub>O<sup>+</sup> and C<sub>2</sub>H<sub>3</sub>O<sub>2</sub><sup>-</sup>

- 43) A 0.1 M solution of which compound is basic?  
 A) sodium chloride, NaCl  
 B) hydrogen chloride, HCl  
 C) sodium carbonate, Na<sub>2</sub>CO<sub>3</sub>  
 D) ammonium chloride, NH<sub>4</sub>Cl  
 E) magnesium sulfate, MgSO<sub>4</sub>

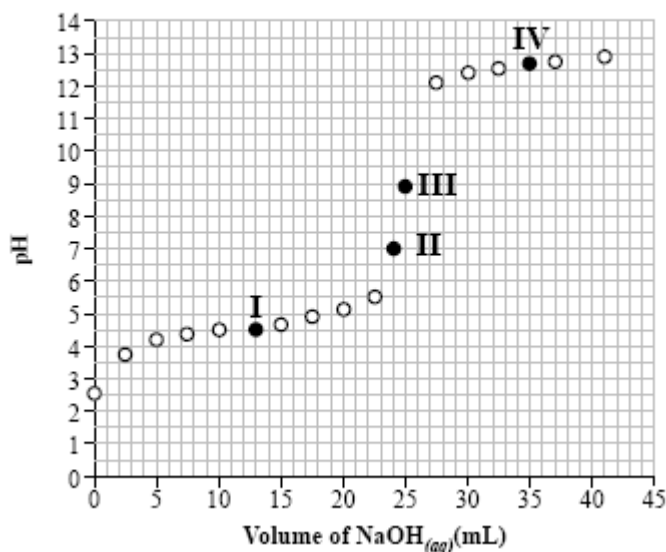
- 44) Balance the following equation in acidic solution and determine the coefficient of H<sup>+</sup> and its location (right or left side) in the equation. **ELIMINATED**



- A) 2, right  
 B) 4, left  
 C) 4, right  
 D) 6, left  
 E) 6, right

- 45) The data for the graph below were recorded by titrating 10.0 mL of vinegar with 0.20 M NaOH.

Titration of 10.0 mL of  $\text{CH}_3\text{COOH}_{(aq)}$  with 0.20 mol/L  $\text{NaOH}_{(aq)}$



On this graph, the equivalence point is indicated by Roman numeral

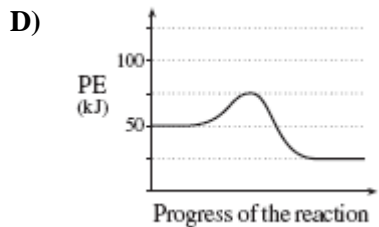
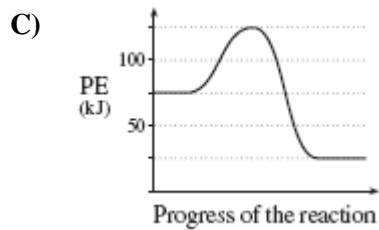
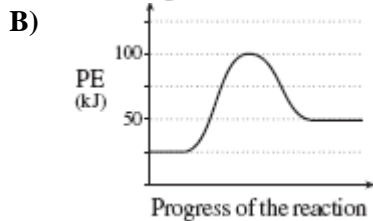
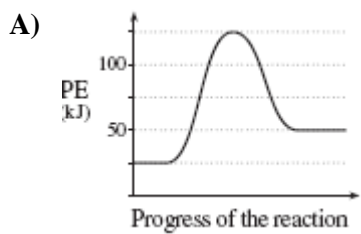
- A) I                      B) II                      C) III                      D) IV

*Use the following information for questions 46,47 and 48.*

When a car is started, the starter motor draws a current from the battery.  
The battery recharges while the car is running.

- 46) Before the car is started, the battery's chemical energy is in the form of  
A) kinetic energy  
B) potential energy  
C) vibrational energy  
D) translational energy  
E) rotational energy
- 47) A car is started and then left running to recharge the battery. In these two processes, the battery  
A) acts as a voltaic cell only  
B) acts as an electrolytic cell only  
C) first acts as an electrolytic cell, then as a voltaic cell  
D) first acts as a voltaic cell, then as an electrolytic cell
- 48) An automotive student obtained 500 mL of acid from a car battery. The student poured 50 mL of the acid into beaker I, 100 mL into beaker II, and then conducted several tests. In this investigation, the student determined that  
A) both solutions conducted an electric current equally  
B) there was a lower  $[\text{H}_3\text{O}^+_{(aq)}]$  in beaker I than in beaker II  
C) magnesium metal reacted more quickly in beaker I than in beaker II  
D) one drop of methyl red produced a deeper red in beaker II than in beaker I

49) Which of the following graphs most likely represents the slowest forward reaction?



50) Consider the following equilibrium:



Initially, 0.800 mol  $\text{N}_2\text{O}$  is placed in a 1.0L container. At equilibrium, the  $[\text{N}_2]$  is found to be 0.780M. What is the value of  $K_{eq}$ ?

- A)  $1.7 \times 10^{-3}$
- B)  $1.5 \times 10^1$
- C)  $5.9 \times 10^2$
- D)  $1.2 \times 10^3$

**The End**