The 62nd Annual
Merck State Science Day Competition
May 22, 2012

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 **55 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, 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)**	**$1dm^3 = 1$ L**
	R = 8.31 kPa-liter/(mole-K)	**PV=nRT**
	R= 8.31 J/(mole-K)	
Specific heat $_{H2O}$ = 4.184 J/g°C		
1 Faraday (ℑ) = 96,500 coulombs/mole		**1 calorie = 4.184 joules**
	= 96,500 joules/volt	**$Q = mc\Delta T$**
1 electron volt/atom = 96.5 kilojoules/mole		**$KE_{ave} = ½mv^2$**
Speed of light in vacuum = 3.00×10^8 m/sec		**K_f water = -1.86 °C/*m***
Planck's constant, h = 6.63×10^{-34} joule-sec		**K_b water = 0.51°C/*m***
Boltzmann's constant, k = 1.38×10^{-23} joule/K		**STP = 0°C, 101.3 kPa**
Avogadro's number = 6.02×10^{23} molecules/mole		

Periodic Table of the Elements

1 H 1.00794																1 H 1.00794	2 He 4.002602
3 Li 6.941	4 Be 9.012182											5 B 10.811	6 C 12.0107	7 N 14.00674	8 O 15.9994	9 F 18.9984032	10 Ne 20.1797
11 Na 22.989770	12 Mg 24.3050											13 Al 26.981538	14 Si 28.0855	15 P 30.973761	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.955910	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938049	26 Fe 55.845	27 Co 58.933200	28 Ni 58.6934	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.92160	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.90550	46 Pd 106.42	47 Ag 107.8682	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.90447	54 Xe 131.29
55 Cs 132.90545	56 Ba 137.327	57 La 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.96655	80 Hg 200.59	81 Tl 204.3833	82 Pb 207.2	83 Bi 208.98038	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 (269)	111 (272)	112 (277)		114 (289) (287)		116 (289)		118 (293)

58 Ce 140.116	59 Pr 140.90765	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92534	66 Dy 162.50	67 Ho 164.93032	68 Er 167.26	69 Tm 168.93421	70 Yb 173.04	71 Lu 174.967
90 Th 232.0381	91 Pa 231.03588	92 U 238.0289	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 (262)

S.E. Van Bramer, 7/22/99

1995 IUPAC masses and Approved Names from http://www.chem.qmw.ac.uk/iupac/AtWt/

masses for 107-111 from C&EN, March 13, 1995, P 35

112 from http://www.gsi.de/z112e.html

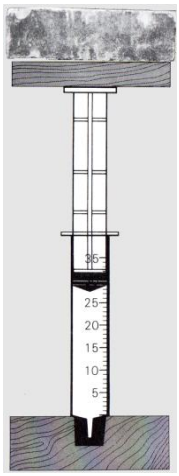
114 from C&EN July 19, 1999

116 and 118 from http://www.lbl.gov/Science-Articles/Archive/elements-116-118.html

Multiple Choice

Identify the choice that best completes the statement or answers the question and place your selection ON THE ANSWER SHEET..

1. Identical bricks are placed on a vertical syringe and the volume of trapped gas is measured and tabulated. See illustration.



bricks	volume, mL
1	28.1
2	21.1
3	17.0
4	14.0
5	12.0

Based on this data, what is the atmospheric pressure in bricks?

A) 0.1
B) 1
C) 2
D) 14.7
E) 101.3

2. For an alkane with ***n*** number of carbons, how much oxygen is required for complete combustion of the alkane?

A) 2n
B) 2n+2
C) 5n/2
D) (3n+1)/2
E) 3(2n+2)/2

3. Electric current flowing through a solution of silver nitrate deposits metallic silver at one electrode and releases oxygen gas at the other electrode. A 5.0 g deposit of silver is obtained after 10 minutes. What battery terminal is the silver connected to and what was the average reading of the ammeter?

A) anode; 2.0 amp
B) cathode; 2.0 amp
C) anode; 7.5 amp
D) cathode; 7.5 amp
E) cathode; 50 amp

4. A solution is made from 100. mL of 0.030 *M* ammonia and 100. mL of 0.050 *M* ammonium chloride. What is the resulting pH? (Assume all volumes are additive.) K_b of ammonia = 1.8×10^{-5}

A) 3
B) 5
C) 7
D) 9
E) 11

5. A certain organic compound is found by analysis to contain 31.9% carbon and 5.30% hydrogen, by weight. A qualitative test shows chlorine to be present as well. When a 4.08-gram sample of this compound is converted to vapor, it is found to occupy 380 mL at 102ºC and 750 mm Hg. What is the molecular formula of the compound?

A) C_6HCl_{12}
B) $C_3H_6Cl_2$
C) $C_9H_{18}Cl_6$
D) C_2H_3Cl
E) none of the above

6. When solid silver chloride is treated with concentrated (15-molar) ammonia solution, what is one of the products?

A) $AgNH_2$
B) NH_4Cl
C) $[Ag(NH_3)_2]^+$
D) $AgNH_4Cl_2$
E) AgOH

7. Which kind of force/bonding is responsible for making calcium fluoride, CaF_2, a solid?

A) covalent bonding
B) vander Waal forces
C) coulombic attractions
D) London dispersion forces
E) metallic bonding

8. Which species would be considered a base in the Lewis concept but not in the Bronsted-Lowry?

A) O^{2-}
B) HSO_4^-
C) Ar
D) HF
E) H^-

9. Nitryl fluoride can be made by treating nitrogen dioxide with fluorine:

$$2\ NO_2(g) + F_2(g) \rightarrow 2\ NO_2F(g)$$

Use the following rate data to calculate the initial rate for Experiment 5.

Experiment	$[NO_2]_0$	$[F_2]_0$	initial rate, mol $L^{-1}s^{-1}$
1	0.001	0.005	$2.0x10^{-4}$
2	0.002	0.005	$4.0x10^{-4}$
3	0.006	0.002	$4.8x10^{-4}$
4	0.006	0.004	$9.6x10^{-4}$
5	0.015	0.003	?

A) $2.5x10^{-2}$
B) $1.8x10^{-3}$
C) $4.5x10^{-4}$
D) $2.7x10^{-5}$
E) $1.8x10^{-5}$

10. Uranium-238, the most abundant of three naturally occurring uranium isotopes, undergoes a decay series that will change it into U-234. What emissions create this isotope?

A) 1 alpha and 1 betas
B) 2 alphas
C) 2 alphas and 1 beta
D) 1 alpha and 2 betas
E) 2 alphas and 2 betas

11. A highly radioactive sample of liquid nuclear waste has a half-life of 200 years and is stored in an underground tank. How can we speed up this decay so that it will be radioactive for a shorter period of time?

I	increase its temperature
II	increase the pressure
III	turn it into a solid
IV	bury it deep underground
V	vaporize it into a gas

A) I and II
B) I and III
C) V only
D) III and IV
E) none of the above

12. The "alum" used in cooking is potassium aluminum sulfate hydrate $KAl(SO_4)_2 \cdot xH_2O$. To find the value of *x*, you can heat the sample of the compound to drive off all the water and leave only the anhydrous compound. Using the data below, what is the value of *x*?

mass of empty crucible	16.23 g
mass of crucible and hydrate	20.97 g
mass of crucible and contents after 1st heating	18.92 g
mass of crucible and contents after 2nd heating	18.82 g
mass of crucible and contents after 3rd heating	18.81 g

A) 1
B) 2
C) 8
D) 9
E) 12

13. When gaseous chlorine is dissolved in water, it undergoes a disproportionation reaction. If one of the products is HClO*(aq)*, what is one of the other products?

A) ClO_2^-
B) ClO_3^-
C) ClO_4^-
D) Cl^-
E) OCl_2

14. Four metals, A, B, C, and D, exhibit the following properties:
(1) only A and C react with 1.0 M hydrochloric acid to give $H_2(g)$
(2) when C is added to solution of the ions of the other metals, metallic B, D, and A are formed.
(3) metal D reduces B^{n+} to give metallic B and D^{n+}
Based on the information, arrange the four metals in order of increasing ability to act as reducing agents.

A) A, B, C, D
B) B, D, A, C
C) B, D, C, A
D) D, B, A, C
E) D, B, C, A

15. Titanium (IV) oxide is converted to titanium carbide with carbon at a high temperature.:

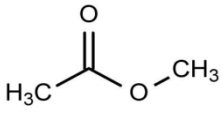
$$TiO_2(s) + 3\ C(s) \rightarrow 2\ CO(g) + TiC(s)$$

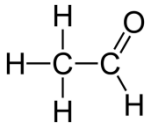
Using the equation the the data below, calculate the value of the equilibrium constant, *K*, at 727°C?

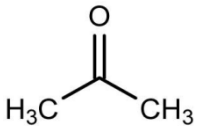
compound	**free energy of formation at 727°C, kJ mol^{-1}**
$TiO_2(s)$	-757.8
TiC(s)	-162.6
CO(g)	-200.2

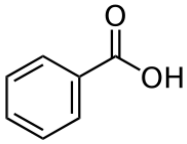
A) 3.88×10^{-1418}
B) 3.49×10^{-1031}
C) 9.92×10^{-15}
D) 6.60×10^{-11}
E) 0.977

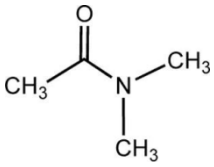
16. Which organic compound would exhibit the strongest hydrogen bonding?

A) methyl acetate, CH_3COOCH_3 

B) acetaldehyde (ethanal), CH_3CHO 

C) acetone (2 propanone), CH_3COCH_3 

D) benzoic acid, C_6H_5COOH 

E) N,N-dimethylacetamide, $CH_3CON(CH_3)_2$ 

~~**17.** When the string of a "Champagne Party Popper" is pulled, the Party Popper detonates. There is a popping noise and a release of streamers. Each party popper contains less than 0.25grains of a mixture of potassium chlorate, antimony sulfide, and phosphorus. The explosion occurs because of the sudden evolution of gaseous sulfur dioxide. The overall reaction is:~~

~~$$KClO_3(s) + Sb_2S_3(s) + P_4(s) \rightarrow KCl(s) + P_4O_{10}(s) + Sb_2O_3(s) + SO_2(g)$$~~

~~When balanced with the smallest whole numbers, what is the sum of coefficents of the **reactants?**~~
Eliminated

~~**A)** 31~~
~~**B)** 34~~
~~**C)** 37~~
~~**D)** 55~~
~~**E)** 92~~

18. Which of these characteristics describes the PCl_3 molecule?

I trigonal planar shape
II sp^3 hybridized phosphorus atom
III polar bonds
IV nonpolar molecule

A) **I** and **II** only
B) **I** and **IV** only
C) **II** and **III** only
D) **I**, **III**, and **IV** only
E) **II** and **IV** only

19. Iron metal tanks buried underground corrode due to acidicty in the soil. This corrosion can be minimized by attaching a *sacrifical block* of magnesium metal by a wire to the tank. The magnesium corrodes instead of the iron tank because

A) the magnesium acts as a cathode, and is oxidized to magnesium ions.
B) the magnesium acts as anode, and is oxidized to magnesium ions.
C) the iron tank behaves as an anode, and plates the surface of the magnesium metal with iron ions.
D) the iron tank behaves as a cathode, and is reduced to iron ions.
E) the iron tank behaves as an anode, and is reduced to iron ions.

20. Which statement is ***false***?

A) A process with $\Delta H < 0$ is more likely to be spontaneous than one with $\Delta H > 0$.
B) The rate law for a reaction is an algebraic expression relating the forward reaction rate to product concentration.
C) Ammonia is an amphoteric substance.
D) The products of a Brønsted-Lowry acid base reaction are always a new acid and a new base.
E) One (1) Faraday is the total charge of one mole of electrons.

21. Some compounds that are insoluble in water dissolve in acids. Which of these compounds is expected to be *more* soluble in an acidic solution than in an equal volume of distilled water?

I. **AgCl** II. **$CaCO_3$** III. **$AlPO_4$**

A) II only
B) Iand III only
C) II and III only
D) I, II, and III
E) none of these

22. During a titration a student has to look upward to read the initial volume of the standard solution in the buret, and has to look downward to read the final volume. Compared to the actual volume of the standard solution that was used, the recorded volume will be

A) the same since the errors cancel out.
B) the same, within experimental error.
C) too high.
D) too low.
E) too high or too low depending on the shape of the meniscus.

23. Given the thermochemical equations:

$$2\ Cu_2O(s) + O_2(g) \rightarrow 4CuO(s) \qquad \Delta H^\circ = -287\ kJ$$
$$Cu_2O(s) \rightarrow CuO(s) + Cu(s) \qquad \Delta H^\circ = 11.3\ kJ$$

What is the standard heat of formation of CuO(s)?

A) -309.6 kJ
B) -154.8 kJ
C) -275.7 kJ
D) +154.8 kJ
E) +298.3 kJ

24. Which formula represents lead(IV) tetraamminedibromosulfate complex?

A) $[Pb(NH_3)_4Br_4]SO_4$
B) $[Pb(NH_3)_4Br_2]SO_4$
C) $[Pb(NH_3)_2Br_4](SO_4)_2$
D) $[Pb(NH_3)_4Br]_2\ SO_4$
E) $[Pb(NH_3)_4Br_2]\ (SO_4)_2$

25. How many isomers of C_3H_8O exist?

A) one **B)** two **C)** three **D)** four **E)** five

26. In an experiment to determine the molecular weight of a condensable vapor, 2.15 grams of an unknown volatile liquid were placed in 0.250 liter flask. A pinhole opening was made in the flask cover to expel excess vapor. The flask was then warmed in a boiling water bath. Given an outside atmospheric pressure of 0.98 atm, when the flask is cooled to condense the vapor, 0.54 grams of liquid were measured when cooled to room temperature.

Given that the mass of the condensed liquid remaining plus the mass of vapor left uncondensed at room temperature is equal to the mass of vapor filling the flask at 100°C, what is the *approximate molecular weight* of this volatile liquid?

A) 49 g mol^{-1}
B) 67 g mol^{-1}
C) 201 g mol^{-1}
D) 269 g mol^{-1}
E) 336 g mol^{-1}

27. The rate law for a reaction is found to be

$$\textbf{rate} = k[A]^2[B]$$

Which statement about this system is correct?

A) A plot of log rate versus time is a straight line.
B) The units for the rate constant are $mol^2\ L^{-2}s^{-1}$
C) This reaction is unlikely since it implies the simultaneous collision of two atoms of A and one of B.
D) It is unlikely that the first step of the mechanism is the rate-limiting step.
E) All third-order reactions are endothermic.

28. According to the Bragg Equation: $2d\sin\theta = n\lambda$, when X-rays of the same wavelength strike two crystals with the same packing but with different atom sizes, the one with smaller atoms will create a diffraction pattern in which the spacing of the points of coincidence

A) is smaller
B) is greater
C) is identical
D) varies with state
E) cannot tell from information

29. Ammonia (NH_3) is found to diffuse 3.865 times faster than which of these gases (assume similar conditions for both diffusing gases)?

A) Br_2
B) PCl_5
C) SF_6
D) I_2
E) UF_6

30. A student has an experimental gas bulb containing: 14.0 g N_2, 64.0 g of O_2, 8.00 g of He, and 142 g of Cl_2, at a total pressure of 380 mm Hg. What is the partial pressure of the helium (He) gas?

A) 34 mm Hg
B) 138 mm Hg
C) 190 mm Hg
D) 190 mm Hg
E) none of these

31. Given: 112 grams of a non-volatile non-electrolyte dissolved in 250 grams of water. If the freezing point of this solution is –26.04°C, what is the formula for this non-volatile non-electrolyte? (χ_{H2O} = 1.86°C m^{-1})

A) CH_4
B) CH_3OH
C) CH_2O
D) CH_3COOH
E) C_2H_5OH

32. Nitrous oxide (N_2O), also called laughing gas, can be prepared from the thermal decomposition of ammonium nitrate. The other product formed is water. If you are given 122.5 grams of ammonium nitrate, how many grams of N_2O can be formed (assume STP)?

A) 28.7 g
B) 44.0 g
C) 67.4 g
D) 80.0 g
E) 222 g

33. The equilibrium constant may be stated in terms of K_c or K_p. How are they related for this reaction?

$$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$$

A) $K_p = K_c$
B) $K_p = K_c(RT)^2$
C) $K_p = K_c(RT)$
D) $K_p = K_c(RT)^{-1}$
E) none of these

34. What is the molar concentration of I^- in 1.0 L of a saturated water solution of PbI_2 (K_{sp} of $PbI_2 = 1.4 \times 10^{-8}$ at 25°C)

A) 9.5×10^{-4}M
B) 1.2×10^{-4}M
C) 1.9×10^{-3}M
D) 3.0×10^{-3}M
E) 3.8×10^{-3}M

35. Rank the following four substances in order of increasing boiling point.

A) $H_2O < Ar < Cl_2 < BrCl$
B) $BrCl < Ar < Cl_2 < H_2O$
C) $Ar < BrCl < H_2O < Cl_2$
D) $Cl_2 < BrCl < H_2O < Ar$
E) $Ar < Cl_2 < BrCl < H_2O$

36. Which substance is amphoteric?

A) HCl
B) LiOH
C) $Al(OH)_3$
D) $HBrO_3$
E) $Mg(ClO)_2$

37. The temperature and the pressure on a sample of water at its triple point is held constant. Which phase changes are favored?

I fusion **II** sublimation **III** vaporization

A) **I** only
B) **III** only
C) **I** and **II** only
D) **II** and **III** only
E) none of these

38. For the burning of ethane gas:

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g) + 2856\ kJ$$

Which is true at any temp.?

I $\Delta G > 0$
II $\Delta S > 0$
III $\Delta H < 0$

A) I only
B) III only
C) II and III only
D) I, II, III
E) none of these

39. What mass of water is needed to dissolve 292.5 g of NaCl to produce a 0.25-molal (*m*) aqueous solution?

A) 0.050 kg
B) 0.80 kg
C) 2.0 kg
D) 5.0 kg
E) 20 kg

40. Which conditions favor the high solubility of a gas in a liquid?

A) low pressure, low temperature
B) low pressure, high temperature
C) high pressure, low temperature
D) high pressure, high temperature
E) pressure and temperature have no influence on solubility

41. Which is the most accurate description of the motion of an electron within an atom?

A) in fixed orbits about the nucleus
B) a distribution of definite locations near the nucleus
C) a cloud-like distribution of probable locations
D) with definite momentum and location
E) in increasing densities approaching the nucleus

42. Adipic acid, $HOOC(CH_2)_4COOH$, is used in making the synthetic polymer nylon. How many atoms are in 1.0 g of adipic acid?

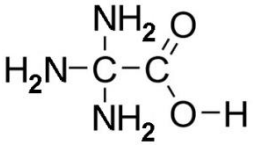
A) 4.8×10^{-21}
B) 20
C) 7.5×10^{22}
D) 8.3×10^{22}
E) 4.9×10^{25}

43. Of the following, which element has the largest 2^{nd} ionization energy?

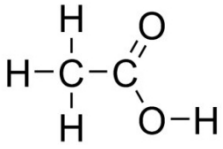
A) F
B) Ne
C) Na
D) Mg
E) Al

44. Which compound has the largest K_a?

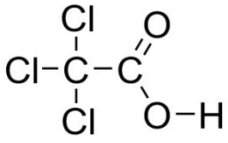
A) $C(NH_2)_3COOH$,



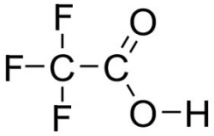
B) CH_3COOH,



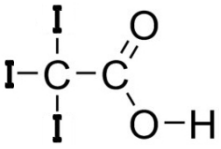
C) CCl_3COOH,



D) CF_3COOH,



E) CI_3COOH,



45. Which statement is true concerning the resonance structure of the carbonate ion?

A) One C-O bond energy is larger than the other two as shown by stretching frequencies the IR spectrum.

B) All three C-O bonds are the same lengths, which is somewhat shorter than a single C-O bond.

C) A sample contains many molecules, each of which has one C-O bond shorter than the other two. Averaging all of these molecules produces an average distance that is somewhat shorter that a single C-O bond.

D) One C-O bond is more reactive than the other two because the double bond is less stable

E) The carbonate ion does not have any resonance structures.

46. A galvanic cell at standard temperature, is made from a Cd strip, a Ag rod coated with AgCl and 1.0 M solutions of $CdCl_2$ and $AgNO_3$, This cell may be described as:

$$Cd(s) \mid Cd^{2+}(1.00\ M) \parallel Ag^{+}\ (1.00\ M) \mid Ag(s)$$

The standard electrode potentials are

$$Cd^{2+}(aq) + 2e^{-} \rightarrow Cd \quad E^{o} = -0.402\ V$$
$$Ag^{+}(aq) + e^{-} \rightarrow Ag \quad E^{o} = 0.799\ V$$

What is the cell voltage if $[Cd^{2+}] = 0.010$ M and $[Ag^{+}] = 0.50$ M?

A) 1.160 V

B) 1.222 V

C) 1.242 V

D) 1.283 V

E) 0, cells only work at standard conditions

47. The scientific law most noted to determine the molal freezing point of a substance is?

A) Raoult's Law

B) Beer's Law

C) Graham's Law

D) Charles' Law

E) Hess's Law

48. The elements that most notably oxidize weakly and serve as good electrical conductors are

A) carbon, oxygen

B) fluorine, chlorine

C) zinc, mercury

D) sodium, potassium

E) silver, gold

49. Which of the following separation techniques would be best used to purify soluble solids?

A) Distillation

B) HPLC Chromatography

C) Filtration

D) Electrolysis

E) Fractional crystallization

50. Which element is commonly added to silicon to improve its semiconducting properties?

A) As **B)** Ni **C)** C **D)** Mn **E)** Br

Matching

Match the molecule or ion to its geometric shape.

A) square pyramidal
B) trigonal planar
C) trigonal pyramidal
D) trigonal bipyramidal
E) T-shaped

51. PF_5

52. BF_3

53. NF_3

54. ClF_3

~~**55.** BF_5~~ Eliminated

END

Merck State Science Day 2012 **CHEMISTRY**
Answer Section

MULTIPLE CHOICE

1. C
2. D
3. D
4. D
5. C
6. C
7. C
8. C
9. B
10. D
11. E
12. E
13. D
14. B
15. D
16. D
17. ~~C~~ Eliminate
18. C
19. B
20. B
21. ~~C~~ A
22. C
23. B
24. B
25. C
26. B
27. D
28. B
29. D
30. ~~B~~ E
31. B
32. C
33. ~~E~~ D
34. D
35. E
36. C
37. E
38. C
39. E
40. C
41. C
42. D
43. C
44. D
45. B
46. C
47. A
48. E
49. E
50. ~~B~~ A
51. D
52. B
53. C
54. E
55. ~~A~~ Eliminate