## The $64^{\text {th }}$ Annual Merck State Science Day Competition May 19, 2014 Chemistry

## DIRECTIONS

The "answer panel" at the bottom of the window is pre-set to show 10 answer boxes per page.
1.The current question has a black border.
2. Enter your answer choice using the keyboard.
3. Click Confirm to record your answer.
4. Questions that have been answered will be tinted Green
5. Any answer can be edited. Confirm the correction.
6.> moves to the next set of questions ( <moves back)
7. Click on any number to answer that question.
8. Confirm all entries. Each answer is recorded only when Confirm is used.
9. When finished, use FINISHED TEST in lower left.

There is a Periodic Table for your use also.
The test has $\underline{\mathbf{7 0}}$ items that will be scored. You have $\underline{\mathbf{9 0}}$ minutes in which to answer all the questions. 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.

Hint: The size of the lettering in the bottom answer panel can be adjusted using CTRL + to magnify the browser view. The TEST view can be adjusted using the size control in the PDF viewer (eg Adobe Reader).

## INFORMATION THAT MAY BE USEFUL IN SOLVING THE PROBLEMS



The Periodic Table of the Elements

| 1 <br> $\substack{\text { Hydiogen } \\ 1.00794}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | He <br> Helium |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3 | 4 |  |  |  |  |  |  |  |  |  |  | 5 | 6 | 7 | 8 | 9 | 10 |
| Li | Be |  |  |  |  |  |  |  |  |  |  | B | C | N | 0 | F | Ne |
| ${ }_{\substack{\text { Litium } \\ 6.941}}^{\text {Len }}$ |  |  |  |  |  |  |  |  |  |  |  | $\underbrace{\text { cin }}_{\substack{\text { Baonn } \\ 10.811}}$ | ${ }_{\substack{\text { catanon } \\ 12.0107}}^{1}$ | ${ }_{\text {Ninegen }}^{\text {14.0667 }}$ | ${ }_{\substack{\text { Oxygen } \\ 15.9994}}^{\text {Ond }}$ |  | ${ }_{\substack{\text { 20.190 } \\ \text { Ne7 }}}^{\text {den }}$ |
| 11 | 12 |  |  |  |  |  |  |  |  |  |  | 13 | 14 | 15 | 16 | 17 | 18 |
| Na | Mg |  |  |  |  |  |  |  |  |  |  | Al | Si | P | S | Cl | Ar |
|  | ${ }_{\substack{\text { Magassium } \\ 24.350}}^{\text {and }}$ |  |  |  |  |  |  |  |  |  |  | ${ }_{\text {and }}^{\text {Aluminum }}$ | ${ }_{\substack{\text { silion } \\ 28.085}}$ | ${ }_{\substack{\text { Phapghans } \\ \text { 30.73761 }}}$ | ${ }_{\substack{\text { sulur } \\ 32.066}}^{\text {and }}$ |  | $\underbrace{\text { and }}_{\substack{\text { Argm } \\ 39.948}}$ |
| 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| $\underbrace{\text { a }}_{\substack{\text { Patasium } \\ \text { 30.0983 }}}$ | ${ }_{\substack{\text { Catiom } \\ 40.078}}^{\substack{\text { cen }}}$ | ${ }_{\text {a }}^{\substack{\text { Samadium } \\ 44.95910}}$ | ${ }_{\text {che }}^{\substack{\text { Thatium } \\ 47.86}}$ |  | Chamim | $\underbrace{}_{\substack{\text { Manganese } \\ 54.388049}}$ | ${ }_{5}^{\text {5 } 5.845}$ | ${ }_{58}^{\text {chabash }}$ | (nitcl | ${ }_{\substack{\text { copper } \\ 63.546}}^{\text {cor }}$ | (ince | ${ }_{\substack{\text { Canlium } \\ 69.23}}^{\substack{\text { a }}}$ | ${ }^{72.61}$ | ${ }_{74.92160}^{\text {Anceric }}$ | ${ }_{\substack{\text { Sclerium } \\ 78.96}}^{\substack{\text { Sem }}}$ |  | $\underbrace{\text { kn }}_{\substack{\text { Krphon } \\ 83.80}}$ |
| 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 |
| Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| $\underbrace{\text { Rem }}_{\substack{\text { Rusudum } \\ 85.4678}}$ | ${ }_{\substack{\text { shentium } \\ 87.62}}^{\substack{\text { Sr }}}$ | ${ }_{88.00585}^{\text {y.num }}$ |  |  | ${ }_{\substack{\text { Maphbeamm } \\ 95.94}}^{\substack{\text { a }}}$ |  |  |  | ${ }_{\substack{\text { Paialama } \\ 106.42}}^{\text {Pd }}$ | (silut | ${ }_{\substack{\text { caimum } \\ 112.411}}^{\text {cat }}$ |  | ${ }_{\substack{\text { tin } \\ 118.710}}^{\text {che }}$ | ${ }_{\substack{\text { Animany } \\ 121.760}}^{\text {Sb }}$ |  |  | ${ }_{\substack{\text { Xenon } \\ 13129}}^{\text {ate }}$ |
| 55 | 56 | 57 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 |
| Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
|  | ${ }_{\substack{\text { Brium } \\ 137.377}}^{\text {Br }}$ | ${ }_{\text {che }}^{\substack{\text { Linatamum } \\ 138.9055}}$ | (Hatium |  | $\underbrace{\text { den }}_{\substack{\text { Thusesen } \\ 183.84}}$ | ${ }_{\substack{\text { Rencium } \\ 186.27}}^{\text {R }}$ | ${ }_{\substack{\text { Onium } \\ \text { Opo23 }}}^{\text {as }}$ |  | ${ }_{\substack{\text { Platiom } \\ 195.078}}^{\substack{\text { a }}}$ |  |  |  | $\substack{\text { Lead } \\ 207.2}_{1 / 2}$ | ${ }_{\substack{\text { Bimamh } \\ 208.98388}}$ | $\underbrace{\text { a }}_{\substack{\text { Polonium } \\ \text { (209) }}}$ | $\underbrace{\text { ate }}_{\substack{\text { asatioc } \\ \text { (210) }}}$ | $\underbrace{\text { a }}_{\substack{\text { Radon } \\ \text { (22) }}}$ |
| 87 | 88 | 89 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 |  |  |  |  |
| Fr | Ra | Ac | Rf | Db | Sg | Bh | Hs | Mt |  |  |  |  |  |  |  |  |  |
| $\underbrace{}_{\substack{\text { Fiancium } \\ \text { (223) }}}$ | ${ }_{\substack{\text { Reatium } \\ \text { (22) }}}$ | (exticium | (261) | ${ }_{\substack{\text { Pubhum } \\ \text { (262) }}}$ |  | (262) | ${ }_{\substack{\text { Hassium } \\(225)}}^{\substack{\text { a }}}$ |  | (269) | (272) | (277) |  |  |  |  |  |  |


| 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Ce <br> Cerium 140.116 |  | $\underset{\substack{\text { Neodymium } \\ 144.24}}{\mathbf{N d}}$ | $\underset{\substack{\text { Promedium } \\(145)}}{\mathbf{P m}}$ | $\underset{\substack{\text { Samarium } \\ 150.36}}{\text { Sm }}$ | $\underset{\substack{\text { Eurpoum } \\ 151.964}}{\text { Euu }}$ | $\underset{\substack{\text { Caddinium } \\ 157.25}}{\mathbf{G d d}}$ | $\underset{\substack{\text { Terbium } \\ 158.9253}}{\mathbf{T b}}$ | $\underset{\substack{\text { Dyyprosium } \\ 1 \\ \text { Dy2.50 }}}{ }$ | $\underset{\substack{\text { Holimum } \\ 164.93032}}{\text { Ho }}$ | $\underset{\substack{\text { Erbium } \\ 167.26}}{\mathbf{E r}}$ | $\underset{\substack{\text { Thulium } \\ 168.93421}}{\mathbf{T m}}$ | $\underset{\substack{\text { Yeterium } \\ 173.04}}{\mathbf{Y b}}$ | $\underset{\substack{\text { Lutecium } \\ \text { 174.967 }}}{\mathbf{L u}}$ |
| 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 |
| Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |
| $\xrightarrow[\substack{\text { Tharium } \\ 232.0381}]{ }$ | ${ }_{\substack{\text { Proactinum } \\ 231.03588}}$ | Uranium 238.0289 | $\begin{gathered} \text { Neptunium } \\ (237) \end{gathered}$ | $\begin{gathered} \text { Plutonium } \\ (2444) \end{gathered}$ | $\underset{\substack{\text { Americium } \\(243)}}{\text { ata }}$ | $\begin{aligned} & \text { Curium } \\ & (247) \end{aligned}$ | Berkelium | Californium | $\begin{gathered} \text { Einsteinium } \\ (252) \end{gathered}$ | $\begin{aligned} & \text { Fermuium } \\ & \text { (257) } \end{aligned}$ | Mendelevium | $\begin{gathered} \text { Nobelium } \\ (259) \end{gathered}$ | $\begin{aligned} & \text { Lawrencium } \\ & (262) \end{aligned}$ |

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

## Multiple Choice

Identify the choice that best completes the statement or answers the question and place your selection ON THE ANSWER PANEL then "Confirm".

1. Which group of elements in the periodic table would be the easiest to oxidize?
A) halogens
B) transuranic
C) alkali metals
D) transition metals
E) alkaline earth metals
2. Which group of elements in the periodic table has the lowest first ionization energy of its period?
A) halogens
B) noble gases
C) lanthanides
D) transuranics
E) alkali metals
3. Which element would have the lowest first ionization energy?
A) N
B) O
C) F
D) Ne
E) He
4. Two substances, A and B, are in a mixture together and could not be separated by distillation even though they have widely different boiling points. What is a possible cause for this?
A) They form an eutectic.
B) They have similar densities.
C) They have similar molar masses
D) They are both covalent molecules
E) They have similar crystal lattice structures.
5. Which gas composes the third most common gas in the earth's atmosphere (dry)?
A) neon
B) argon
C) ozone
D) methane
E) carbon dioxide
6. Which is the correct symbol for a species with 53 protons, 76 neutrons, and 54 electrons?
A) ${ }_{54}^{129} \mathrm{Xe}$
B) ${ }_{53}^{129} \mathrm{I}$
C) ${ }_{76}^{129} \mathrm{Os}$
D) ${ }_{53}^{129} \mathrm{Os}^{-}$
E) ${ }_{54}^{129} \mathrm{Xe}$

Question 7

7. The structure above represents citronella, a compound obtained from lemongrass and used extensively in soaps, candles, incense, perfume and cosmetics. What functional group is present in the molecule?
A) ester
B) amine
C) carboxyl
D) hydroxyl
E) double bond
8. Which compound has both ionic and covalent bonds?
A) methane
B) chloromethane
C) calcium bromide
D) potassium iodide
E) ammonium chloride
9.


The energy level diagram represents a hydrogen atom. Which energy transition would emit a photon with the shortest wavelength?
A) $5 \rightarrow 4$
B) $4 \rightarrow 2$
C) $3 \rightarrow 2$
D) $2 \rightarrow 1$
E) $1 \rightarrow 2$

10.

Above is the photoelectron spectrum (PES) of an unknown element. What is the most likely charge that this element would form as an ion?
A) -1
B) +1
C) -7
D) +7
E) +2
11. Which property generally increases across the $2^{\text {nd }}$ row of the periodic table from lithium to neon?
A) density
B) polarity
C) atomic radius
D) ionization energy
E) oxidation number
12. The species $\mathrm{F}^{-}, \mathrm{Ne}, \mathrm{Na}^{+}$all have the same number of electrons. What is the correct order when arranged from largest to smallest in size (radius)?
A) $\mathrm{F}^{-}>\mathrm{Ne}>\mathrm{Na}^{+}$
B) $\mathrm{Ne}>\mathrm{Na}^{+}>\mathrm{F}^{-}$
C) $\mathrm{Na}^{+}>\mathrm{F}^{-}>\mathrm{Ne}$
D) $\mathrm{F}^{-}>\mathrm{Na}^{+}>\mathrm{Ne}$
E) $\mathrm{Na}^{+}>\mathrm{Ne}>\mathrm{F}^{-}$
13. What happens when an atom of hydrogen absorbs a photon of light?
A) An electron changes spin direction.
B) An electron is converted into a proton.
C) An electron jumps to a higher energy level.
D) The hydrogen atom bonds to another atom.
E) The photon makes the nucleus vibrate.
14. Which compound would have the most ionic character?
A) sodium chloride, NaCl
B) silicon dioxide, $\mathrm{SiO}_{2}$
C) phosphorus trichloride, $\mathrm{PCl}_{3}$
D) carbon tetrachloride, $\mathrm{CCl}_{4}$
E) boron trifluoride, $\mathrm{BF}_{3}$
15. Which bond would be the MOST polar?
A) $\mathrm{C}-\mathrm{O}$
B) $\mathrm{H}-\mathrm{O}$
C) $\mathrm{H}-\mathrm{F}$
D) $\mathrm{C}-\mathrm{N}$
E) $\mathrm{F}-\mathrm{O}$
16. Which molecule has a double bond?
A) $\mathrm{C}_{2} \mathrm{H}_{6}$
B) $\mathrm{CH}_{3} \mathrm{OCH}_{2} \mathrm{CH}_{3}$
C) $\mathrm{N}_{2}$
D) $\mathrm{Cl}_{2}$
E) $\mathrm{C}_{3} \mathrm{H}_{6}$
17. $2 \mathrm{SO}_{3} \rightleftarrows 2 \mathrm{SO}_{2}+\mathrm{O}_{2}$ (all gases)

After the equilibrium represented above is established, some pure $\mathrm{O}_{2}(\mathrm{~g})$ is injected into the reaction vessel at constant temperature. After equilibrium is reestablished, which has a LOWER value compared to its value at the original equilibrium?
A) $K_{c}$ for the reaction
B) the total pressure in the reaction vessel
C) the amount of $\mathrm{SO}_{3}(\mathrm{~g})$ in the reaction vessel
D) the amount of $\mathrm{O}_{2}(\mathrm{~g})$ in the reaction vessel
E) the amount of $\mathrm{SO}_{2}(\mathrm{~g})$ in the reaction vessel
18. Which equilibrium can be described as an acid-base reaction using the Lewis acid-base definitions, but NOT using the Brønsted-Lowry definitions?
A) $\mathrm{NH}_{3}+\mathrm{CH}_{3} \mathrm{COOH} \rightleftarrows \mathrm{CH} 3 \mathrm{COO}-+\mathrm{NH}_{4}{ }^{+}$
B) $\mathrm{H}_{2} \mathrm{O}+\mathrm{CH}_{3} \mathrm{COOH} \rightleftarrows \mathrm{H} 3 \mathrm{O}++\mathrm{CH}_{3} \mathrm{COO}^{-}$
C) $4 \mathrm{NH}_{3}+\mathrm{Cu}\left(\mathrm{H}_{2} \mathrm{O}\right)_{4}{ }^{2+} \rightleftarrows \mathrm{Cu}\left(\mathrm{NH}_{3}\right)_{4}{ }^{2+}+4 \mathrm{H}_{2} \mathrm{O}$
D) $2 \mathrm{NH}_{3}+\mathrm{H}_{2} \mathrm{SO}_{4} \rightleftarrows 2 \mathrm{NH}_{4}{ }^{+}+\mathrm{SO}_{4}{ }^{2-}$
E) $\mathrm{Fe}\left(\mathrm{H}_{2} \mathrm{O}\right)_{6}{ }^{3+}+\mathrm{H}_{2} \mathrm{O} \rightleftarrows \mathrm{H}_{3} \mathrm{O}^{+}+\mathrm{Fe}\left(\mathrm{H}_{2} \mathrm{O}\right) 5(\mathrm{OH})^{2+}$
19. Which property is characteristic of the hydroxides of zinc, aluminum, and tin?
A) insoluble in $\mathrm{NH}_{3}(\mathrm{aq})$
B) amphoteric
C) crystalline precipitates
D) colored
E) soluble in water
20. A 0.10 M solution of potassium acetate, $\mathrm{KC} 2 \mathrm{H}_{3} \mathrm{O}$ 2, is less alkaline than a 0.10 M solution of potassium cyanide, KCN. What can be concluded from this fact?
A) Hydrocyanic acid is a weaker acid than acetic acid.
B) Hydrocyanic acid is less soluble in water than acetic acid.
C) Cyanides are less soluble than acetates.
D) KCN ionizes to give three ions; $\mathrm{KC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ ionizes to give eight ions.
E) Acetic acid is a weaker acid than hydrocyanic acid.
21. Which statement provides the best experimental evidence for the fact that acetic acid is a weaker acid than hydrobromic acid?
A) Acetic acid tends to donate protons to a basic solvent more strongly than does HBr .
B) In the bond in HBr the electrons are shifted more towards the bromine than they are towards the oxygen in the corresponding $\mathrm{H}-\mathrm{O}$ bond in acetic acid.
C) Inorganic acids are stronger than organic acids.
D) Zinc reacts more rapidly with 0.1 M HBr than with 0.1 M acetic acid.
E) Less NaOH is required to neutralize a mole of acetic acid than to neutralize a mole of HBr .
22. In the early part of the $20^{\text {th }}$ Century, Ernest Rutherford conducted a series of landmark experiments where he shot alpha particles at a gold foil target. Most of the particles were undeflected. According to Rutherford, what did this indicate?
A) The gold foil was continuous matter.
B) The mass of the gold atoms was spread out thinly.
C) The atoms of gold were mostly empty space.
D) The alpha particles had great penetrating power.
E) The alpha particles had charges opposite to those on the nuclei.
23. What experimental evidence indicates the existence of discrete (quantized) energy levels of electrons in an atom?
A) experiments on the photoelectric effect
B) diffraction of electrons by crystals
C) X-ray diffraction by crystals
D) K capture by the nucleus
E) magnetic resonance imaging
24. Which is/are a property of an ionic compound but NOT of a covalent compound.
I. high melting point
II. insoluble in nonpolar solvents
III. when aqueous it will depress the freezing point of the water
IV. conducts current when dissolved in water
V. soluble in polar solvents
A) I and IV
B) IV only
C) I, II, III, IV
D) III only
E) all of them
25. Which model is used to explain the paramagnetism of $\mathrm{O}_{2}$ molecules?
A) molecular orbital model
B) valence bond model
C) Lewis electron-pair model
D) ionic model
E) Bohr model
26. Which grouping of elements, compounds, or ions are isoelectronic?
A) $\mathrm{Li}, \mathrm{Na}, \mathrm{K}$
B) $\mathrm{F}^{-}, \mathrm{Cl}^{-}, \mathrm{Br}^{-}$
C) $\mathrm{CO}_{2}, \mathrm{NO}_{2}, \mathrm{ClO}_{2}$
D) $\mathrm{CO}, \mathrm{N}_{2}, \mathrm{NO}^{+}$
E) $\mathrm{Mn}, \mathrm{Fe}, \mathrm{Co}$
27. Why are aqueous solutions of fluorides difficult to oxidize at the anode of an electrolytic cell?
A) The fluorides are not very soluble.
B) In salts the fluoride ion has a plus charge
C) The aqueous solutions of fluorides are nonconducting.
D) Oxygen is released from water in preference to fluorine.
E) It is impossible to find the proper material from which to build the electrodes.
28. The same quantity of electricity is passed through 1 M solutions of HCl and of $\mathrm{H}_{2} \mathrm{SO}_{4}$ at different temperatures. The number of grams of hydrogen evolved from the $\mathrm{H}_{2} \mathrm{SO}_{4}$ solution, compared to that evolved from the HCl solution, is
A) the same.
B) twice as much.
C) one half as much.
D) a function of the molarity of the solutions.
E) a function of the temperature of the solutions.
29. A solution of $\mathrm{CdSO}_{4}$ is electrolyzed between inert electrodes. How many hours must a current of 1.75 A flow to deposit 11.8 g of cadmium?
A) 0.51 hr
B) 1.26 hr
C) 3.22 hr
D) 5.18 hr
E) 6.44 hr
30. Given:

$$
\mathrm{Mg}(s)+\mathrm{Br}_{(l)} \rightarrow \mathrm{Mg}^{2+}{ }_{(a q)}+2 \mathrm{Br}^{-}(a q)
$$

Which statement is correct regarding a galvanic cell based on the reaction above?
A) $\mathrm{The} \mathrm{Br} \mid \mathrm{Br}^{-}$electrode is the anode
B) $\mathrm{Mg}^{2+}$ ions migrate towards the cathode.
C) An increase in concentration of $\mathrm{Mg}^{2+}$ would increase the cell voltage.
D) The electrons enter the magnesium electrode from the external circuit.
E) Electrons move through the solution going from the magnesium electrode to the $\mathrm{Br}_{2} \mid \mathrm{Br}^{-}$electrode.

| Standard Reduction Potentials, $E_{0}$ |  |  |
| :--- | :---: | :---: |
| $\mathrm{Mg} \rightarrow \mathrm{Mg}^{2+}+2 e_{-}$ | 2.37 V |  |
| $\mathrm{Al} \rightarrow \mathrm{Al}^{3+}+3 e_{-}$ | 1.66 V |  |
| $\mathrm{Zn} \rightarrow \mathrm{Zn}^{2+}+2 e_{-}$ | 0.76 V |  |
| $\mathrm{Fe} \rightarrow \mathrm{Fe}^{2+}+2 e_{-}$ | 0.44 V |  |
| $\mathrm{Cu} \rightarrow \mathrm{Cu}^{2+}+2 e_{-}$ | -0.34 V |  |
| $\mathrm{Ag} \rightarrow \mathrm{Ag}^{+}+e_{-}$ | -0.80 V |  |

31. Using only the metals $\mathrm{Mg}, \mathrm{Al}, \mathrm{Zn}, \mathrm{Fe}, \mathrm{Cu}$ and Ag , together with their 1 M salt solutions, what is the highest possible voltage of a voltaic cell constructed using electrodes of these metals?
A) 0.71 V
B) 1.57 V
C) 3.17 V
D) 4.05 V
E) 6.33 V
32. Salt and vinegar potato chips are flavored with sodium chloride (salt) and sodium acetate (vinegar powder). If individual $1-M$ solutions of these compounds are measured, what would be the pH of each solution?
pH of solution
sodium chloride sodium acetate
A) 7,9
B) 7,5
C) 5,4
D) 7,7
E) 9,4
33. The equilibrium constant for the gaseous reaction

$$
\mathbf{C}+\mathbf{D} \rightleftarrows \mathbf{E}+2 \mathbf{F}
$$

is 3.0 at $50^{\circ} \mathbf{C}$. In a 2.0 L flask at $50^{\circ} \mathrm{C}$ are placed 1.0 mol of $\mathbf{C}, 1.0 \mathrm{~mol}$ of $\mathbf{D}, 1.0 \mathrm{~mol}$ of $\mathbf{E}$, and 3.0 mol of $\mathbf{F}$. Initially, how will this reaction proceed?
A) equal rates in both directions
B) more rapidly to form $\mathbf{E}$ and $\mathbf{F}$
C) more rapidly to form $\mathbf{C}$ and $\mathbf{D}$
D) not occur in either direction
E) direction depends on the activation energy
34. A mixture of 2.0 mol of $\mathrm{CO}_{(\mathrm{g})}$ and 3.0 mol of $\mathrm{H}_{2} \mathrm{O}_{(\mathrm{g})}$ was allowed to come to equilibrium in a 2.0L flask at a high temperature. If $K_{c}=4.0$, what is the molar concentration of $\mathrm{H}_{2}(g)$ in the equilibrium mixture?

$$
\mathrm{CO}_{(g)}+\mathrm{H}_{2} \mathrm{O}_{(g)} \rightleftarrows \mathrm{CO}_{2(g)}+\mathrm{H}_{2}(g)
$$

A) 0.63 M
B) 0.78 M
C) 1.3 M
D) 1.6 M
E) 2.4 M
35. Which name/formula pairing is correct?
A) ferric bicarbonate, $\mathrm{Fe}\left(\mathrm{CO}_{3}\right)_{2}$
B) stannous dichromate, tin(IV) chromate(II)
C) gold phosphate, $\mathrm{Au}_{2} \mathrm{PO}_{4}$
D) cupric sulfate, $\mathrm{CuSO}_{4}$
E) mercurous nitrite, $\mathrm{MeNO}_{2}$
36. When white phosphorous reacts with nitric acid and water, it produces phosphoric acid and nitrogen(II) oxide. When the equation is balanced with smallest whole number coefficients, what is the sum of the coefficients?
A) 12
B) 17
C) 18
D) 32
E) 63
37. Three different chloride compounds having the formulas $\mathrm{KCl}, \mathrm{MgCl}_{2}$, and $\mathrm{FeCl}_{3}$ exist. What does this indicate?
A) The chlorine atom can accept 1,2 , or 3 electrons
B) Combined chlorine has a positive oxidation number.
C) The combining capacity of chlorine varies.
D) The combining capacities of the metals are different
E) Chlorine has more than one oxidation number.
38. Which assumption(s) is/are made concerning the kinetic molecular theory of an ideal gas?
I. particle collisions are perfectly elastic
II. particles travel at the same speed
III. intermolecular forces $=0$
IV. particulate volume $=0$
A) II only
B) I \& II only
C) III \& IV only
D) II \& III only
E) I, III, and IV only
39. Identical containers $\boldsymbol{A} \& \boldsymbol{B}$ are at the same pressure and temperature. $\boldsymbol{A}$ contains carbon dioxide and $\boldsymbol{B}$ contains propane. Which statement and reason is correct?
A) They have the same temperature because the molecules in both containers have the same average velocity.
B) Container $\boldsymbol{A}$ has more molecules because the particles are smaller.
C) The London dispersion forces in container $\boldsymbol{B}$ are greater because propane is a heavier molecule.
D) They have the same pressure because they have the same number of molecules.
E) They have the same pressure because they are both non-polar gases.

40. For an ideal gas, the graph above could represent a plot of
A) $V$ vs. $T$, at constant $P$
B) $P$ vs. $T$, at constant V
C) $P$ vs. V, at constant $T$
D) K.E. vs. $T$, at constant $P$
E) molecular velocity vs. $T$, at constant P \& V
41. The density of a gas at 0.855 atm and $25.0^{\circ} \mathrm{C}$ is $1.54 \mathrm{~g} / \mathrm{L}$. What is this gas?
A) helium
B) neon
C) ammonia
D) carbon dioxide
E) sulfur hexafluoride
42. The Joule-Thomson effect (cooling of a real gas expanding into a vacuum with subsequent liquefaction of the gas) is an indication that
A) gases have IMF.
B) most gases show "ideal" behavior at low pressure.
C) molecular gases generally contain covalent bonds.
D) most di- and triatomic gases are "greenhouse" gases.
E) gas temperatures need to be measured using the Kelvin scale.
43. The temperature of a sample of gas in a rigid container is raised from $100^{\circ} \mathrm{C}$ to $200^{\circ} \mathrm{C}$ and it's pressure doubled. What can we infer from this behavior?
A) The gas behaved like an ideal gas.
B) The gas is diatomic.
C) Some of the gas condensed.
D) Some of the gas decomposed.
E) The gas has a weak IMF.
44. Who first determined Avogadro's Number?
A) Amadeo Avogadro
B) Robert Boyle
C) Stanislao Cannizzaro
D) Jean Baptist Emil Litre
E) Josef Loschmidt
45.

$$
E=E^{\circ}-0.0592 \log Q
$$

In the lead-acid storage cell (e.g., car battery), this reaction takes place

$$
\mathrm{Pb}_{(s)}+\mathrm{PbO}_{2(s)}+2 \mathrm{H}^{+}(a q)+2 \mathrm{HSO}_{4}^{-}(a q) \rightarrow 2 \mathrm{PbSO}_{4}(s)+2 \mathrm{H}_{2} \mathrm{O}_{(l)}
$$

At $25^{\circ} \mathrm{C}$, the standard cell potential is 2.04 V . What is the electromotive force at $25^{\circ} \mathrm{C}$ of a fully charged storage cell having $3.70 \mathrm{M} \mathrm{H}^{+}$and $3.70 \mathrm{M} \mathrm{HSO}_{4}{ }^{-}$?
A) 1.46 V
B) 1.97 V
C) 2.04 V
D) 2.11 V
E) 2.18 V

46. Which pair of safety glasses/goggles is/are acceptable in a chemistry lab?
A) IV only
B) III \& IV
C) II, III, and IV
D) all of them
E) goggles are not required if you wear your eyeglasses
47. The rate equation for a chemical reaction is determined by
A) the balanced reaction equation.
B) measuring reaction rate as a function of concentration of reacting species.
C) determining the equilibrium constant for the reaction.
D) measuring reaction rates as a function of temperature.
E) whether it is a composition or decomposition reaction.
48. The table presents data for the reaction:

$$
2 \mathrm{H}_{2}(g)+2 \mathrm{NO}(g) \xrightarrow{k_{1}} 2 \mathrm{H}_{2} \mathrm{O}(g)+\mathrm{N}_{2}(g)
$$

The temperature of the reaction is constant. [The initial rate is in arbitrary units.]

| Exp. | Initial <br> $[\mathrm{NO}] \times 10^{-3}$ | Concentration <br> $\left[\mathrm{H}_{2}\right] \times 10^{-3}$ | Initial <br> Rate |
| :--- | :---: | :---: | :---: |
| I | 6.0 | 1.0 | 18 |
| II | 3.0 | 0.67 | 3.0 |
| III | 1.0 | 6.0 | 3.0 |
| IV | 2.0 | 3.0 | 6.0 |

A) rate $=k_{1}\left[\mathrm{H}_{2}\right]^{1 / 2}[\mathrm{NO}]$
B) rate $=k_{1}\left[\mathrm{H}_{2}\right][\mathrm{NO}]$
C) rate $=k_{1}\left[\mathrm{H}_{2}\right]_{2}[\mathrm{NO}]$
D) rate $=k_{1}\left[\mathrm{H}_{2}\right]_{2}[\mathrm{NO}]_{2}$
E) $\quad$ rate $=k_{1}\left[\mathrm{H}_{2}\right][\mathrm{NO}]_{2}$
49.The reaction

$$
2 \mathrm{~N}_{2} \mathrm{O}_{5} \rightarrow 4 \mathrm{NO}_{2}+\mathrm{O}_{2} \quad \text { (all gases) }
$$

is first order. The rate constant is $0.35 \mathrm{~min}^{-1}$. If the initial concentration if $0.160 \mathrm{~mol} \cdot \mathrm{~L}^{-1}$, what is the time required for half of the sample to decompose?
A) 0.080 min
B) 0.175 min
C) 0.35 min
D) 0.70 min
E) 2.0 min
50. For the gaseous reaction

$$
\mathrm{CO}+\mathrm{Cl}_{2} \rightarrow \mathrm{COCl}_{2}
$$

this mechanism has been proposed

$$
\begin{array}{ll}
\mathrm{Cl}_{2} \rightarrow 2 \mathrm{Cl} & \text { fast } \\
\mathrm{Cl}+\mathrm{CO} \rightarrow \mathrm{COCl} & \text { fast } \\
\mathrm{Cl}_{2}+\mathrm{COCl} \rightarrow \mathrm{COCl}_{2}+\mathrm{Cl} & \text { slow }
\end{array}
$$

What is the rate expression for the reaction?
A) rate $=k\left[\mathrm{Cl}_{2}\right]^{2}$
B) rate $=k[\mathrm{CO}]\left[\mathrm{Cl}_{2}\right]$
C) rate $=k[\mathrm{CO}]\left[\mathrm{Cl}_{2}\right]^{3 / 2}$
D) rate $=k[\mathrm{CO}][\mathrm{Cl}]$
E) rate $=k[\mathrm{COCl}]\left[\mathrm{Cl}_{2}\right]^{2 / 3}$
51. An aqueous solution of $\mathrm{Ag}^{+}, \mathrm{Pb}^{2+}$, and $\mathrm{Hg}^{2+}$ is precipitated by the addition of $\mathrm{Cl}^{-}$. What is the best way to dissolve the silver chloride precipitate?
A) add water and heat
B) use an organic solvent
C) add concentrated ammonia
D) add concentrated sulfuric acid
E) add Tollens' reagent and expose to UV light
52. Which aqueous ion is NOT a shade of green?
A) iron(II), $\mathrm{Fe}^{2+}$
B) nickel(II), $\mathrm{Ni}^{2+}$
C) vanadium(III), $\mathrm{V}^{3+}$
D) manganate( VI ), $\mathrm{MnO}_{4}{ }^{2-}$
E) copper(II)-ammonium complex, $\mathrm{Cu}\left(\mathrm{NH}_{3}\right)_{4}{ }^{2+}$

A mixture of two liquids is heated and allowed to boil to dryness while the temperature was recorded and plotted below.

53. What can be interpreted from this plot?
A) This is normal behavior for a mixture.
B) An eutectic mixture was formed.
C) The mixture is an azeotrope.
D) The two liquids are immiscible.
E) The two liquids have the same heat of vaporization, $\Delta H_{\text {vap }}$
54. A bottle of rubbing alcohol is labeled as $90 \%$ isopropyl alcohol (2-propanol, IPA) by volume ( $10 \%$ water). How much water should be added to 450 mL of this mixture to make it $70 \%$ IPA?
[Assume volumes are additive.]
A) 20 mL
B) 45 mL
C) 90 mL
D) 129 mL
E) 135 mL
55. Which species is a product when $\mathrm{I}_{2}$ is reacted with a hot, concentrated, aqueous NaOH solution?
A) $\mathrm{I}^{-}$
B) $\mathrm{H}_{2}$
C) $\mathrm{IO}_{3}{ }^{-}$
D) $\mathrm{O}_{2}$
E) HOI
56. Which pair is geometrically similar?
A) $\mathrm{SO}_{2}$ and $\mathrm{CO}_{2}$
B) $\mathrm{PH}_{3}$ and $\mathrm{BF}_{3}$
C) $\mathrm{CO}_{2}$ and $\mathrm{OF}_{2}$
D) $\mathrm{SO}_{2}$ and $\mathrm{O}_{3}$
E) $\mathrm{IO}_{3}{ }^{-}$and $\left[\mathrm{CuCl}_{4}\right]^{-}$

| Atomic Masses |  |
| :--- | :---: |
| 12 C | 12.00386 u |
| ${ }^{12} \mathrm{H}$ |  |
| 1.00813 u |  |
| ${ }^{13} \mathrm{~F}$ |  |

57. From the equation below and the values of the masses above calculate the energy emitted per molar mass of N formed in the nuclear reaction:

$$
{ }_{6}^{12} \mathrm{C}+{ }_{1}^{1} \mathrm{H} \rightarrow{ }_{7}^{13} \mathrm{~N}+\text { energy }
$$

A) $0.00380 \times\left(3 \times 10^{8}\right)^{2} \times 10^{-3} \mathrm{~J}$
B) $0.00876 \times\left(3 \times 10^{8}\right)^{2} \times 10^{-3} \mathrm{~J}$
C) $0.99557 \times\left(3 \times 10^{8}\right)^{2} \times 10^{-3} \mathrm{~J}$
D) $0.99937 \times\left(3 \times 10^{8}\right)^{2} \times 10^{-3} \mathrm{~J}$
E) $1.00427 \times\left(3 \times 10^{8}\right)^{2} \times 10^{-3} \mathrm{~J}$
58. In the cyclotron bombardment of ${ }_{13}^{27} \mathrm{~A} 1$ with low energy alpha particles, one of the two reaction products is ${ }_{15}^{30} \mathrm{P}$. The other is
A) a proton.
B) a neutron.
C) a meson.
D) a neutrino.
E) a Higgs boson.
59. Ten grams of ethyl acetate are boiled with 100 g of water. What are the two new substances formed?
A) acetaldehyde and ethane
B) ethyl alcohol and ethane
C) diethyl ether and acetic acid
D) ethyl alcohol and acetic acid
E) ethyl alcohol and acetaldehyde

Succinate dehydrogenase or succinate-coenzyme $Q$ reductase ( SQR ) is an enzyme of the citric acid cycle that catalyzes the oxidation of succinate to fumarate.
60. Which species would be the best competitive inhibitor for this enzyme?


A)

B)

C)

propanedioate
D)


Succinyl chloride
E)


| Standard Reduction Potentials $E^{\circ}$ |  |
| :--- | :---: |
| $2 \mathrm{H}++\mathbf{X}+2 e_{-} \rightarrow \mathrm{H}_{2} \mathbf{X}$ | -0.72 V |
| $2 \mathrm{H}_{+}+\mathbf{Y}+2 e_{-} \rightarrow \mathrm{H}_{2} \mathbf{Y}$ | -0.40 V |
| $2 \mathrm{H}_{+}+\mathbf{Z}+2 e_{-} \rightarrow \mathrm{H}_{2} \mathbf{Z}$ | +0.14 V |
| $2 \mathrm{H}_{+}+\mathbf{Q}+2 e_{-} \rightarrow \mathrm{H}_{2} \mathbf{Q}$ | +1.23 V |

61. Which reaction will occur if each substance is in its standard state?
A) $\mathbf{X}$ will oxidize $\mathrm{H}_{2} \mathbf{Y}$ to give $\mathbf{Y}$.
B) $\mathbf{Y}$ will oxidize $\mathrm{H}_{2} \mathbf{Z}$ to give $\mathbf{Z}$.
C) $\mathbf{Z}$ will oxidize $\mathrm{H}_{2} \mathbf{Q}$ to give $\mathbf{Q}$.
D) $\mathbf{Q}$ will oxidize $\mathrm{H}_{2} \mathbf{Y}$ to give $\mathbf{Y}$.
E) none of the above
62. In which pair of particles is the first member larger (radius) than the second member?
A) $\mathrm{Li}^{+} ; \mathrm{Be}^{2+}$
B) $\mathrm{Li}^{+} ; \mathrm{Na}^{+}$
C) $\mathrm{Li}^{+} ; \mathrm{Li}$
D) $\mathrm{Be} ; \mathrm{Mg}$
E) $\mathrm{I}^{-} \mathrm{I}^{-}$
63. Among the alkali metals, cesium reacts more rapidly than sodium. To what may this be ascribed?
A) Cesium has more electrons.
B) Cesium has a higher atomic weight.
C) Cesium has a higher nuclear charge.
D) Cesium is never found in nature in its elemental form.
E) The valence electron in cesium is at a greater average distance from the nucleus.
64. When one mole of naphthalene is dissolved in 1000 g of benzene, the freezing point changes from $5.51^{\circ} \mathrm{C}$ to $0.41^{\circ} \mathrm{C}$. When 20 g of an unknown organic compound is dissolved in 500 g of benzene, the freezing point of this solution is $5.00^{\circ} \mathrm{C}$. What is the molar mass of the unknown organic compound?
A) $40 \mathrm{~g} \cdot \mathrm{~mol}-1$
B) $100 \mathrm{~g} \cdot \mathrm{~mol}-1$
C) $128 \mathrm{~g} \cdot \mathrm{~mol}-1$
D) $200 \mathrm{~g} \cdot \mathrm{~mol}-1$
E) $400 \mathrm{~g} \cdot \mathrm{~mol}-1$
65. Which best explains the stabilizing effect of egg yolk on a emulsion of oil in water?
A) The egg yolk reduces the charge on the oil particles.
B) The egg yolk is adsorbed at the interface between the oil droplets ad the water to prevent coalescence of the droplets.
C) The egg yolk causes bigger droplets of oil to be formed as the emulsion ages.
D) The egg yolk lowers the freezing point of the emulsion.
E) The egg yolk makes a good foam with the water.
66. A 17.0 g sample of impure nickel metal reacts at STP with 25.0 L of CO to form 6.25 L of $\mathrm{Ni}(\mathrm{CO})_{4}$ gas, What is the percentage of Ni in the metal sample? [Impurities are non-reactive.]
$\mathrm{Ni}=58.7 \mathrm{~g} \cdot \mathrm{~mol}^{-1} \mathrm{Ni}(\mathrm{CO}) 4171 . \mathrm{g} \cdot \mathrm{mol}^{-1}$
A) $24.1 \%$
B) $25.0 \%$
C) $86.3 \%$
D) $96.4 \%$
E) more data is need to determine the answer.
67. A 1.20 L sample is drawn from a bottle labeled " $86.0 \%$ by weight $\mathrm{H}_{2} \mathrm{SO}_{4}$, density $1.787 \mathrm{~g} \cdot \mathrm{~mL}^{-1}$ ". What is the molarity of the sample?
A) 1.28 M
B) 8.78 M
C) 10.5 M
D) 15.70 M
E) 18.2 M
68. A 1.00 g sample of $\mathrm{NH}_{4} \mathrm{NO}_{3}$ is decomposed in a bomb calorimeter. The heat capacity of the system is $1.23 \mathrm{~kJ} \cdot \mathrm{~K}^{-1}$.


The temperature starts at $21.33^{\circ} \mathrm{C}$ and increases to $27.45^{\circ} \mathrm{C}$. What is the molar heat of decomposition for ammonium nitrate?
A) $-602 \mathrm{~kJ} \cdot \mathrm{~mol}^{-1}$
B) $-398 \mathrm{~kJ} \cdot \mathrm{~mol}^{-1}$
C) $7.53 \mathrm{~kJ} \cdot \mathrm{~mol}^{-1}$
D) $164 \mathrm{~kJ} \cdot \mathrm{~mol}^{-1}$
E) $602 \mathrm{~kJ} \cdot \mathrm{~mol}^{-1}$
69. Given:
$\mathrm{V}(\mathrm{s})+2 \mathrm{Cl}_{2}(\mathrm{~g}) \rightarrow \mathrm{VCl}_{4}(\mathrm{I}) \quad \Delta H=-569.4 \mathrm{~kJ}$
$\mathrm{VCl}_{3}(\mathrm{~s}) \rightarrow \mathrm{VCl}_{2}(\mathrm{~s})+1 / 2 \mathrm{Cl}_{2}(\mathrm{~g}) \quad \Delta H=+128.9 \mathrm{~kJ}$
$2 \mathrm{VCl}_{3}(\mathrm{~s}) \rightarrow \mathrm{VCl}_{2}(\mathrm{~s})+\mathrm{VCl}_{4}(I) \quad \Delta H=+140.2 \mathrm{~kJ}$
What is the heat of formation of $\mathrm{VCl}_{3}(s)$ ?
A) -300.3 kJ
B) +300.3 kJ
C) -580.7 kJ
D) +580.7 kJ
E) -558.1 kJ
70. 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 $G_{(I)}$, the free energy per mole of the liquid?
A) $G_{(s)}$ is less than $G_{(I)}$
B) $G_{(s)}$ is greater than $G_{(1)}$
C) $G_{(s)}$ equals $0, G_{(l)}$ equals 0
D) $G_{(s)}$ equals $G_{(I) ;}$ neither equals 0
E) $G_{(s)}$ equals $G_{(1)} ; K_{e q}=1 ; \Delta E=0$

