1. Which atom has the greatest (most negative) **electron affinity** of As, Cs, F, N, Ne?
   .
   A) As
   B) N
   C) Cs
   D) F
   E) Ne

2. When the following reaction is balanced in **basic** media, the coefficient for **OH^-** is:
   $MnO_4^- + S_2O_4^{2-} \rightarrow MnO_2 + SO_4^{2-}$
   .
   A) 2
   B) 0
   C) 4
   D) 1
   E) 3

3. The perxenate anion, XeO_6^{4-}, has been isolated in the form of several salts including Na_4XeO_6. Which of the following statements is **FALSE** regarding the charge-minimized Lewis structure of XeO_6^{4-}?
   .
   A) There are 16 electrons involved in bonds
   B) The Xe-O bond order is 4/3
   C) The average formal charge on oxygen is –2/3
   D) There are exactly 6 resonance structures for XeO_6^{4-}
   E) There are no lone electron pairs on Xe

4. If three solutions containing 1.635 g of $NaClO_4$, 2.362 g of Rb_2S and 0.796 g of $CuCl_2$, respectively, are mixed together, if a precipitate forms, what would be its **mass**?
.
A) 2.396 g
B) 0.566 g
C) 1.267 g
D) 3.673 g
E) A precipitate does not form

5. In Beaker A, 0.50 g of AgCl ($K_{sp} = 1.0\times10^{-10}$) was added to 100.0 mL of water containing 0.25 g NaCl. In Beaker B, 0.50 g of AgCl was added to 100.0 mL of pure water. Which of the following statements is **CORRECT?**
.
A) More AgCl dissolves in Beaker A
B) More AgCl dissolves in Beaker B
C) K_{sp} of AgCl is larger for Beaker B
D) There is no effect on K_{sp} and equal amounts of AgCl dissolve in Beakers A and B
E) K_{sp} of AgCl is larger for Beaker A

6. Pure NOBr(g) is introduced in an evacuated container. It dissociates according to the following equilibrium:
$$2\ NOBr(g) \rightleftharpoons 2\ NO(g) + Br_2(g)$$
When equilibrium is established at 25°C, NOBr is 34% dissociated and the total pressure is 0.25 atm. What is ***K*** for this equilibrium?
.
A) 9.9×10^{-6}
B) 0.0096
C) 0.013
D) 0.28
E) 0.036

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7. How much **heat** (in kJ) is required to convert 36.0 g of liquid H_2O at 50.0°C to gaseous H_2O at 100.0°C? $\Delta H_{vaporization}$ for H_2O (l) = 44.0 kJ/mol. The specific heat of water is 4.184 J g^{-1} °C^{-1}.
.
A) 47.8
B) 7.65×10^3
C) 95.5
D) 8.56
E) 78.0

8. Solid ammonium nitrite is added to an initially evacuated container. It decomposes according to the chemical equilibrium,
$$NH_4NO_2(s) \rightleftharpoons N_2(g) + 2\ H_2O(g).$$
Which of the following statements are **FALSE** regarding this equilibrium?
.
A) Removing water (via a drying agent) does not affect the amount of $NH_4NO_2(s)$.
B) Adding more $NH_4NO_2(s)$ to the container does not affect the partial pressure of $N_2(g)$.
C) Reducing the volume of the container increases the amount of $NH_4NO_2(s)$.
D) Pumping additional $N_2(g)$ into the container increases the amount of solid ammonium nitrite.
E) The partial pressure of water in the container is twice that of nitrogen.

9. Identify the **ONE FALSE** statement regarding the electrochemical cell
$$Co(s)\ |\ CoSO_4\ (1.00\ M)\ ||\ Fe(NO_3)_3\ (1.00\ M)\ ,\ Fe(NO_3)_2\ (1.00\ M)\ |\ Pt(s)\ ,$$
for which E_{cell} = +1.05 V. The cell contains a KCl salt bridge.
.
A) Increasing the concentration of $CoSO_4(aq)$ reduces the cell potential.
B) K^+ ions from the salt bridge migrate to the cathode.
C) Pt(s) is the cathode.
D) Fe^{3+} ions migrate toward the Pt(s) electrode.
E) The Co^{2+} concentration decreases during operation of the cell.

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10. A **concentration cell** is used to measure the concentration of Zn^{2+} in a saturated solution of $ZnCO_3$. The saturated solution is at the anode, while there is a 1.0 mol L^{-1} solution of $Zn(NO_3)_2$ at the cathode. If the measured voltage of the cell is 0.321 V at 298 K, what is the **molar solubility** of $ZnCO_3$ at 298 K in mol L^{-1}?

.

A) 3.6×10^{-12}
B) 7.8×10^{-12}
C) 2.1×10^{-10}
D) 1.4×10^{-11}
E) 5.1×10^{-9}

11. What **potential**, in volts, is developed by the following electrochemical cell at 298 K?

$$Al(s) \mid Al^{3+}(0.00100\ M) \parallel Cu^{2+}(0.00100\ M) \mid Cu(s)$$

$Al^{3+}(aq) + 3e^{-} = Al(s)$ $E°_{red} = -1.66V$
$Cu^{2+}(aq) + 2e^{-} = Cu(s)$ $E°_{red} = +0.34$ V
(Hint: balance the cell reaction before you proceed.)

.

A) 2.01
B) 1.95
C) 2.00
D) 1.97
E) 2.07

12. What is the **standard enthalpy of formation** of $PCl_3(g)$ (in kJ mol^{-1})? (Note that $P_4(s)$ is the standard state of phosphorus.)

$P_4(s) + 10\ Cl_2(g) \rightarrow 4\ PCl_5(s)$ $\Delta H° = -1774.0$ kJ
$PCl_3(g) + Cl_2(g) \rightarrow PCl_5(s)$ $\Delta H° = -156.5$ kJ

.

A) +474.0
B) +1517.5
C) –1517.5
D) –287.0
E) +287.0

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13. One mole of Ar gas is compressed by an external pressure of 2.00 atm, to a final volume of 10.0 L from an initial volume of 20.0 L. Using calorimetry, 1.00 kJ of heat is observed to flow from the gas during the compression. What is the change in energy of the gas**, ΔU (in kJ)**?

.

A) –5.06
B) 5.06
C) 1.03
D) 2.43
E) –1.03

14. Considering the data below, identify the **FALSE** statement(s).
$\Delta H_f°$ of B(g) = 563 kJ mol^{-1}
bond enthalpy (F-F) = 159 kJ mol^{-1}
bond enthalpy (B-F) = 646 kJ mol^{-1}

i. $2\ B(s) + 3\ F_2(g) \rightarrow 2\ BF_3(g)$ is a redox reaction.
ii. The reaction $2\ B(s) + 3\ F_2(g) \rightarrow 2\ BF_3(g)$ has $\Delta G < 0$ and $\Delta H > 0$.
iii. $B(s) \rightarrow B(g)$ is an endothermic process.
iv. $\Delta H[\ F_2(g) \rightarrow 2\ F(g)\ ] = -159$ kJ mol^{-1}.

.

A) ii, iv
B) iii, iv
C) i, ii
D) i, iii
E) ii, iii

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15. As it is written, is the following reaction **endothermic** or **exothermic,** and is work done **on** or **by** the system?

$$N_2O_{4\,(g)} \rightarrow 2\ NO_{2(g)}$$

.

A) endothermic; by
B) exothermic; by
C) endothermic; on
D) $\Delta H = 0$; by
E) exothermic; on

16. Estimate the **enthalpy change** (in kJ) of the following gas-phase reaction. (Hint: write the Lewis structures of the molecules before using the given bond enthalpies.)

$$2\ C_2H_4(g) \rightarrow C_2H_2(g) + C_2H_6(g)$$

Bond enthalpies (kJ mol^{-1}): C-C 348; C=C 619; C≡C 812; C-H 413

.

A) +29
B) –166
C) +78
D) –29
E) –78

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17. Student #1 reacted 1.000 mol of reactant A with excess B. A calorimeter with a heat capacity of 16.736 kJ/°C was used and the temperature rose from 23.6 °C to 46.2 °C.
Student #2 performed the same reaction but using 1.094 g of reactant A in a coffee cup calorimeter that contained a 100.0 mL solution of excess B. The temperature rose from 23.40 °C to 29.03 °C.
Assuming the mass of reactant A must be included in the mass of the solution and that the density and specific heat of the solution are equal to those of pure water (density = 1.00 g mL^{-1}, specific heat = 4.184 J g^{-1} $°C^{-1}$), what was the **molar mass** of reactant A (in g mol^{-1})?
.
A) 1090
B) 563
C) 174
D) 256
E) 63.5

18. When the **conjugate base of a weak acid** (in the form of a salt) is dissolved in water, one can conclude:
.
A) there is 100% conversion of conjugate base back to weak acid.
B) $[A^-] < [HA]$
C) $[H_3O^+] > [OH^-]$
D) $K_a = K_b$
E) pH > 7

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19. NaF (2.6 g) is dissolved in 250 mL of water. What is the **pH** of the solution?
K_a (HF) = 6.6×10^{-4}
.
A) 8.29
B) 9.15
C) 10.45
D) 5.34
E) 11.68

20. The following reaction proceeds to 99 % completion. Which of the following species is the **strongest** acid?

$$LiNH_2\ (s) + H_2O\ (l) \rightarrow NH_3\ (g) + LiOH\ (s)$$

.
A) Not enough information
B) $LiNH_2$
C) H_2O
D) NH_3
E) LiOH

21. Which of the following, when dissolved in water would **not dissociate 100%**?
.
A) $HClO_4$
B) HI
C) NH_4^+
D) HCl
E) HBr

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22. A 0.35 M solution of a weak monoprotic acid has a pH of 2.18.
What is the **% dissociation** of the acid?
.
A) 0.83 %
B) 2.1 %
C) 4.3 %
D) 0.058 %
E) 1.9 %

23. What is the **conjugate base** of OH^-?
.
A) H_3O^+
B) O^-
C) OH^- does not have a conjugate base
D) H_2O
E) O^{2-}

24. A student uses an ice calorimeter to monitor an acid base neutralization reaction. If a limiting amount of monoprotic acid, 0.20 mol, is added to excess base, causing 5.5 g of ice to melt (heat of fusion for ice = 333 J g^{-1}), what is the **molar heat of reaction**?
.
A) –320 kJ
B) –48 kJ
C) –1.8 kJ
D) –9.2 kJ
E) –25 kJ

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25. A **Brønsted-Lowry base** is best defined as a species that:

.

A) Produces OH^{-}(aq) when dissolved in water.
B) Produces H^{+}(aq) dissolved in water
C) Produces H^{-}(aq) when dissolved in water.
D) Donates H^{+} during an acid base reaction
E) Accepts H^{+} during an acid base reaction

26. Which of the following is the **strongest base**?

.

A) $HSeO_4^{-}$
B) ClO_4^{-}
C) $HSeO_3^{-}$
D) HSO_3^{-}
E) HSO_4^{-}

27. The K_{sp} of $Cd(OH)_2 = 2.5\times10^{-14}$. What is the **pH** of a saturated solution of cadmium hydroxide?

.

A) 10.65
B) 11.19
C) 8.93
D) 9.57
E) 10.22

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28. In the lab you find that sulfur dioxide reacts with water to give an acidic solution. The reaction is $SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$. Use the thermochemical information given below to calculate the **standard Gibbs free energy** (in kJ mol^{-1}) of this hydration reaction at 298 K.

	$H_2O(l)$	$SO_2(g)$	$H_2SO_3(aq)$
$\Delta H_f°$ / (kJ mol^{-1})	–285.83	–296.83	–627.98
$S°$ / (J $mol^{-1}K^{-1}$)	69.91	248.22	132.38

.

A) –10.0
B) +90.7
C) –90.7
D) +10.0
E) +55.3

29. Identify the reaction with the **largest positive $\Delta S°$**.

.

A) $PCl_5(g) \rightarrow PCl_3(g) + Cl_2(g)$
B) $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$
C) $N_2(g) + 3\ H_2\ (g) \rightarrow 2\ NH_3(g)$
D) $KClO_4(s) + 4\ C(s) \rightarrow KCl(s) + 4\ CO(g)$
E) $H_2O(s) \rightarrow H_2O(g)$

30. Choose the **FALSE** statement.

.

A) A process for which $\Delta H_{sys} > 0$ and $\Delta S_{sys} < 0$ is not spontaneous at any temperature.
B) A process for which $\Delta S_{sys} > 0$ is spontaneous at sufficiently high temperatures.
C) A process for which $\Delta H_{sys} < 0$ is spontaneous at sufficiently low temperatures.
D) $\Delta G_{sys} = 0$ for melting of copper at the melting point of copper.
E) $\Delta G_{sys} < 0$ for melting of copper at temperatures below the melting point of copper.

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31. Which of the following are **TRUE** statements regarding a **spontaneous reaction** at constant temperature and pressure?
    i. $\Delta S_{univ} < 0$
    ii. $\Delta G_{sys} < 0$
    iii. $\Delta S_{sys} > \Delta H_{sys} / T$
    iv. $Q > K$
    .
    A) all
    B) i, ii, iv
    C) i, iii
    D) ii, iii
    E) ii, iv

32. Identify the **FALSE** statement(s):
    i. Mixing together aqueous solutions of NaCl and KCl at constant temperature results in an increase of entropy.
    ii. $S°$(chlorine gas) > $S°$(nitrogen gas).
    iii. Freezing of water causes an increase in the entropy of the surroundings.
    .
    A) i, iii
    B) i, ii
    C) ii, iii
    D) none of these statements is false
    E) all of the statements are false

33. Choose the **FALSE** statement regarding entropy.
    .
    A) The change in entropy between initial and final states does not depend on the path taken by them.
    B) At $T = 0$ K, a perfect crystal has zero entropy.
    C) Entropy is an intensive property. In other words, it does not depend on the amount of substance present.
    D) The processes of melting and boiling are accompanied by positive changes of entropy of the substance.
    E) A spontaneous process always implies an increase in the entropy of the universe.

34. The melting point of tungsten, 3407°C, is the second highest among the elements. The enthalpy of fusion (i.e. melting) of tungsten is 35.2 kJ mol^{-1}. What is the **entropy of fusion (in J mol^{-1} K^{-1})** of tungsten?

.

A) –10.7
B) +10.7
C) +109
D) –9.56
E) +9.56

35. Calculate the **standard entropy of formation (in J mol^{-1} K^{-1})** of NH_3(g) from the standard entropies given below.

	N_2(g)	H_2(g)	NH_3(g)
S^o / (J $mol^{-1}K^{-1}$)	191.6	130.7	192.5

.

A) +139.4
B) –99.4
C) –139.4
D) +192.5
E) –168.1

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