

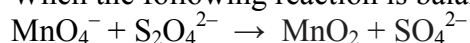
Name: \_\_\_\_\_

Student number: \_\_\_\_\_

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<sup>-</sup>** is:



- A) 2
- B) 0
- C) 4
- D) 1
- E) 3

3. The perxenate anion,  $\text{XeO}_6^{4-}$ , has been isolated in the form of several salts including  $\text{Na}_4\text{XeO}_6$ . Which of the following statements is **FALSE** regarding the charge-minimized Lewis structure of  $\text{XeO}_6^{4-}$ ?

- 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  $\text{XeO}_6^{4-}$
- E) There are no lone electron pairs on Xe

Name: \_\_\_\_\_

Student number: \_\_\_\_\_

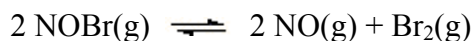
4. If three solutions containing 1.635 g of  $\text{NaClO}_4$ , 2.362 g of  $\text{Rb}_2\text{S}$  and 0.796 g of  $\text{CuCl}_2$ , respectively, are mixed together, if a precipitate forms, what would be its **mass**?

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  $\text{AgCl}$  ( $K_{sp} = 1.0 \times 10^{-10}$ ) was added to 100.0 mL of water containing 0.25 g  $\text{NaCl}$ . In Beaker B, 0.50 g of  $\text{AgCl}$  was added to 100.0 mL of pure water. Which of the following statements is **CORRECT**?

A) More  $\text{AgCl}$  dissolves in Beaker A  
B) More  $\text{AgCl}$  dissolves in Beaker B  
C)  $K_{sp}$  of  $\text{AgCl}$  is larger for Beaker B  
D) There is no effect on  $K_{sp}$  and equal amounts of  $\text{AgCl}$  dissolve in Beakers A and B  
E)  $K_{sp}$  of  $\text{AgCl}$  is larger for Beaker A

6. Pure  $\text{NOBr(g)}$  is introduced in an evacuated container. It dissociates according to the following equilibrium:



When equilibrium is established at  $25^\circ\text{C}$ ,  $\text{NOBr}$  is 34% dissociated and the total pressure is 0.25 atm. What is **K** for this equilibrium?

A)  $9.9 \times 10^{-6}$   
B) 0.0096  
C) 0.013  
D) 0.28  
E) 0.036

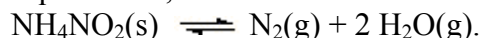
Name: \_\_\_\_\_

Student number: \_\_\_\_\_

7. How much **heat** (in kJ) is required to convert 36.0 g of liquid H<sub>2</sub>O at 50.0°C to gaseous H<sub>2</sub>O at 100.0°C?  $\Delta H_{\text{vaporization}}$  for H<sub>2</sub>O (l) = 44.0 kJ/mol. The specific heat of water is 4.184 J g<sup>-1</sup> °C<sup>-1</sup>.

- A) 47.8  
B)  $7.65 \times 10^3$   
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,



Which of the following statements are **FALSE** regarding this equilibrium?

- A) Removing water (via a drying agent) does not affect the amount of NH<sub>4</sub>NO<sub>2</sub>(s).  
B) Adding more NH<sub>4</sub>NO<sub>2</sub>(s) to the container does not affect the partial pressure of N<sub>2</sub>(g).  
C) Reducing the volume of the container increases the amount of NH<sub>4</sub>NO<sub>2</sub>(s).  
D) Pumping additional N<sub>2</sub>(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

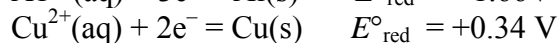
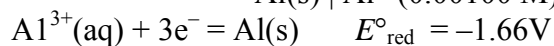
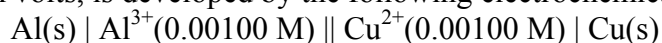
Co(s) | CoSO<sub>4</sub> (1.00 M) || Fe(NO<sub>3</sub>)<sub>3</sub> (1.00 M) , Fe(NO<sub>3</sub>)<sub>2</sub> (1.00 M) | Pt(s) ,  
for which  $E_{\text{cell}} = +1.05 \text{ V}$ . The cell contains a KCl salt bridge.

- A) Increasing the concentration of CoSO<sub>4</sub>(aq) reduces the cell potential.  
B) K<sup>+</sup> ions from the salt bridge migrate to the cathode.  
C) Pt(s) is the cathode.  
D) Fe<sup>3+</sup> ions migrate toward the Pt(s) electrode.  
E) The Co<sup>2+</sup> concentration decreases during operation of the cell.

10. A **concentration cell** is used to measure the concentration of  $\text{Zn}^{2+}$  in a saturated solution of  $\text{ZnCO}_3$ . The saturated solution is at the anode, while there is a  $1.0 \text{ mol L}^{-1}$  solution of  $\text{Zn(NO}_3)_2$  at the cathode. If the measured voltage of the cell is  $0.321 \text{ V}$  at  $298 \text{ K}$ , what is the **molar solubility** of  $\text{ZnCO}_3$  at  $298 \text{ K}$  in  $\text{mol L}^{-1}$ ?

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

11. What **potential**, in volts, is developed by the following electrochemical cell at  $298 \text{ K}$ ?



(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  $\text{PCl}_3(\text{g})$  (in  $\text{kJ mol}^{-1}$ )? (Note that  $\text{P}_4(\text{s})$  is the standard state of phosphorus.)



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

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,  $\Delta U$  (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).

$$\Delta H_f^\circ \text{ of B(g)} = 563 \text{ kJ mol}^{-1}$$

$$\text{bond enthalpy (F-F)} = 159 \text{ kJ mol}^{-1}$$

$$\text{bond enthalpy (B-F)} = 646 \text{ kJ mol}^{-1}$$

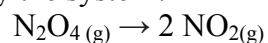
- i.  $2 \text{ B(s)} + 3 \text{ F}_2(\text{g}) \rightarrow 2 \text{ BF}_3(\text{g})$  is a redox reaction.  
ii. The reaction  $2 \text{ B(s)} + 3 \text{ F}_2(\text{g}) \rightarrow 2 \text{ BF}_3(\text{g})$  has  $\Delta G < 0$  and  $\Delta H > 0$ .  
iii.  $\text{B(s)} \rightarrow \text{B(g)}$  is an endothermic process.  
iv.  $\Delta H[ \text{F}_2(\text{g}) \rightarrow 2 \text{ F(g)} ] = -159 \text{ kJ mol}^{-1}$ .

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

Name: \_\_\_\_\_

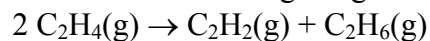
Student number: \_\_\_\_\_

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



- .  
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.)



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

- .  
A) +29  
B) -166  
C) +78  
D) -29  
E) -78

Name: \_\_\_\_\_

Student number: \_\_\_\_\_

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<sup>-1</sup>, specific heat = 4.184 J g<sup>-1</sup> °C<sup>-1</sup>), what was the **molar mass** of reactant A (in g mol<sup>-1</sup>)?

- .  
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)  $pH > 7$

Name: \_\_\_\_\_

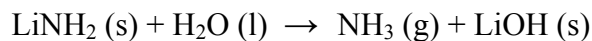
Student number: \_\_\_\_\_

19. NaF (2.6 g) is dissolved in 250 mL of water. What is the **pH** of the solution?

$$K_a(\text{HF}) = 6.6 \times 10^{-4}$$

- .  
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?



- .  
A) Not enough information  
B)  $\text{LiNH}_2$   
C)  $\text{H}_2\text{O}$   
D)  $\text{NH}_3$   
E)  $\text{LiOH}$

21. Which of the following, when dissolved in water would **not dissociate 100%**?

- .  
A)  $\text{HClO}_4$   
B)  $\text{HI}$   
C)  $\text{NH}_4^+$   
D)  $\text{HCl}$   
E)  $\text{HBr}$



Name: \_\_\_\_\_

Student number: \_\_\_\_\_

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  $\text{OH}^-$ ?

.  
A)  $\text{H}_3\text{O}^+$   
B)  $\text{O}^-$   
C)  $\text{OH}^-$  does not have a conjugate base  
D)  $\text{H}_2\text{O}$   
E)  $\text{O}^{2-}$

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 =  $333 \text{ J g}^{-1}$ ), what is the **molar heat of reaction**?

.  
A)  $-320 \text{ kJ}$   
B)  $-48 \text{ kJ}$   
C)  $-1.8 \text{ kJ}$   
D)  $-9.2 \text{ kJ}$   
E)  $-25 \text{ kJ}$

Name: \_\_\_\_\_

Student number: \_\_\_\_\_

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

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

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

- A)  $\text{HSeO}_4^-$
- B)  $\text{ClO}_4^-$
- C)  $\text{HSeO}_3^-$
- D)  $\text{HSO}_3^-$
- E)  $\text{HSO}_4^-$

27. The  $K_{sp}$  of  $\text{Cd}(\text{OH})_2 = 2.5 \times 10^{-14}$ . 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

Name: \_\_\_\_\_

Student number: \_\_\_\_\_

28. In the lab you find that sulfur dioxide reacts with water to give an acidic solution. The reaction is  $\text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_3(\text{aq})$ . Use the thermochemical information given below to calculate the **standard Gibbs free energy** (in  $\text{kJ mol}^{-1}$ ) of this hydration reaction at 298 K.

	$\text{H}_2\text{O}(\text{l})$	$\text{SO}_2(\text{g})$	$\text{H}_2\text{SO}_3(\text{aq})$
$\Delta H_f^\circ / (\text{kJ mol}^{-1})$	-285.83	-296.83	-627.98
$S^\circ / (\text{J mol}^{-1}\text{K}^{-1})$	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  $\Delta S^\circ$** .

- A)  $\text{PCl}_5(\text{g}) \rightarrow \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$   
B)  $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$   
C)  $\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g}) \rightarrow 2 \text{NH}_3(\text{g})$   
D)  $\text{KClO}_4(\text{s}) + 4 \text{C}(\text{s}) \rightarrow \text{KCl}(\text{s}) + 4 \text{CO}(\text{g})$   
E)  $\text{H}_2\text{O}(\text{s}) \rightarrow \text{H}_2\text{O}(\text{g})$

30. Choose the **FALSE** statement.

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

31. Which of the following are **TRUE** statements regarding a **spontaneous reaction** at constant temperature and pressure?

- i.  $\Delta S_{\text{univ}} < 0$
- ii.  $\Delta G_{\text{sys}} < 0$
- iii.  $\Delta S_{\text{sys}} > \Delta H_{\text{sys}} / T$
- 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.  $S^\circ(\text{chlorine gas}) > S^\circ(\text{nitrogen gas})$ .
- 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  $T = 0 \text{ K}$ , 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.

Name: \_\_\_\_\_

Student number: \_\_\_\_\_

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

- .  
A)  $-10.7$   
B)  $+10.7$   
C)  $+109$   
D)  $-9.56$   
E)  $+9.56$

35. Calculate the **standard entropy of formation (in  $\text{J mol}^{-1} \text{ K}^{-1}$ )** of  $\text{NH}_3(\text{g})$  from the standard entropies given below.

	$\text{N}_2(\text{g})$	$\text{H}_2(\text{g})$	$\text{NH}_3(\text{g})$
$S^{\circ} / (\text{J mol}^{-1} \text{ K}^{-1})$	191.6	130.7	192.5

- .  
A)  $+139.4$   
B)  $-99.4$   
C)  $-139.4$   
D)  $+192.5$   
E)  $-168.1$