

1. Calculate the change in molar Gibbs free energy and state if the process is spontaneous for  $\text{NH}_3(\text{l}) \rightarrow \text{NH}_3(\text{g})$  at 1 atm and a)  $-15^\circ\text{C}$ , b)  $-45^\circ\text{C}$ ?

$$\Delta H_{\text{vap}}^\circ = 23.4 \text{ kJ} \cdot \text{mol}^{-1}$$

$$T_b = 239.7 \text{ K}$$

$$\text{We use: } \Delta G_m = \Delta H_m - T\Delta S_m$$

$$\Delta S_{\text{vap}} = \frac{\Delta H_{\text{vap}}}{T_b} = \frac{23.4 \text{ kJ}}{239.7 \text{ K mol}} = 97.62 \frac{\text{J}}{\text{K mol}}$$

a)  $T = -15^\circ\text{C} = 258.15 \text{ K}$

$$\Delta G_m = \Delta H_{\text{vap},m} - T\Delta S_{\text{vap},m} = 23.4 \text{ kJ} \cdot \text{mol}^{-1} - 258.15 \text{ K} \cdot 0.09762 \frac{\text{kJ}}{\text{K mol}}$$

$$\Delta G_m = 23.4 \text{ kJ} \cdot \text{mol}^{-1} - 25.2 \text{ kJ} \cdot \text{mol}^{-1} \approx -1.8 \text{ kJ} \cdot \text{mol}^{-1}$$

$\Delta G_m < 0$ : **spontaneous**

b)  $T = -45^\circ\text{C} = 228.15 \text{ K}$

$$\Delta G_m = 23.4 \text{ kJ} \cdot \text{mol}^{-1} - 22.3 \text{ kJ} \cdot \text{mol}^{-1} \approx 1.1 \text{ kJ} \cdot \text{mol}^{-1}$$

$\Delta G_m > 0$ : **non-spontaneous**

2. A student rides a bicycle to class every day, a round trip of 10 miles that takes 30 minutes in each direction. the student burns 420 kJ/h cycling. the same round trip in an automobile would require 0.4 gallons of gasoline. Assume that the student goes to class 150 days per year and that the enthalpy of combustion of gasoline can be approximated by that of octane ( $\text{C}_8\text{H}_{18}$ ;  $H_{\text{comb}} = -5470 \text{ kJ} \cdot \text{mol}^{-1}$ ), which has a density of  $0.702 \text{ g/cm}^3$ . What is the yearly energy requirement in KWh of that journey by a) bicycle, b) automobile?

Please note:  $1 \text{ W h} = 3600 \text{ J}$ ;  $1 \text{ gallon} = 3.785 \text{ L}$

a) Bicycle

$$\text{Energy/trip} = 420 \text{ kJ/h} \cdot 1 \text{ h} = 420 \text{ kJ}$$

$$\text{Energy/year} = 420 \text{ kJ} \cdot 150 = 63000 \text{ kJ} = 63 \text{ MJ} = \mathbf{17.5 \text{ kWh}}$$

$$\text{with } 1 \text{ W h} = 3600 \text{ J} \text{ or } 1 \text{ kWh} = 3600 \text{ kJ}$$

b)  $0.4 \text{ gallons} \cdot 150 \text{ trips/year} = 60 \text{ gallons/year}$

$$m_{\text{tot}} = 60 \text{ gal} \cdot 3785 \text{ ml/gallon} \cdot 0.72 \text{ g/ml} = 159.42 \text{ kg}$$

$$n_{\text{octane}} = \frac{m_{\text{tot}}}{M_{\text{octane}}} = \frac{159.42 \text{ kg}}{114 \frac{\text{g}}{\text{mol}}} = 1398 \text{ mol}$$

$$E = n \cdot 5470 \frac{\text{kJ}}{\text{mol}} = 7.64 \text{ GJ} = \mathbf{2121 \text{ kWh}}$$

3. Which of the elements has atoms with the greatest polarizability?

A) carbon

B) aluminium

C) argon

D) germanium

Germanium has the most shells, it is the heaviest, and it is also the largest.

A) Which of the elements has the greatest electron affinity?

- A) oxygen
- B) sulphur
- C) gallium
- D) tellurium

Oxygen is smaller, and it has a greater effective nuclear charge so other atoms will feel oxygen's pull on their electrons.

4. Which of the following pairs have about the same atomic radius?

- A) Cu and Ag
- B) Co and Rh
- C) Fe and Ru
- D) Ru and Os

Ru and Os have very similar radii due to lanthanide contraction.

5. Metal hydrides are often used to remove traces of water from nonpolar solvents. What is the balanced chemical equation for the reaction of calcium hydride with water?

- A)  $\text{CaH}_2 (\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca}(\text{OH})_2(\text{s}) + 2 \text{H}_2 (\text{g})$
- B)  $\text{CaH}_2 (\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CaOH} (\text{s}) + \text{H}_3\text{O}^+ (\text{aq})$
- C)  $\text{CaH}_2 (\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca}(\text{s}) + 2\text{H}_3\text{O}^+ (\text{aq})$
- D)  $\text{CaH}_2 (\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca}(\text{s}) + \text{O}_2(\text{g}) + 6 \text{H}^+ (\text{aq})$

Metal hydrides always produce hydrogen gas. Thus answer A) is the correct one.

6. What is the element in Period 3 that forms an amphoteric oxide with the formula  $\text{E}_2\text{O}_3$  where E is the element of interest?

- A) sodium
- B) aluminum
- C) sulfur
- D) phosphorous

B. aluminum,  $\text{Al}_2\text{O}_3$

7. What type of material would gallium (Group 13) doped with germanium (Group 14) make?

- A. semiconductor
- B. superconductor
- C. n-type conductor
- D. p-type conductor

**n-type conductor:** The germanium increases the number of electrons in the solid:

each gallium atom has three valence electrons while each germanium atom has four. The additional electrons enter the upper conduction band of gallium, enabling the solid to conduct.

8. What type of material would antimony (Group 15) doped with tin (Group 14) make?
- semiconductor
  - superconductor
  - n-type conductor
  - p-type conductor

**p-type conductor:** Antimony has five valence electrons while tin only has four. The electron-poor dopant atoms remove electrons from the valence band. The valence band is now said to contain “holes” and since the valence band is no longer full, it has been turned into a conduction band, and an electric current can flow.

9. Which bond distance is longer:
- the Li-Cl distance in lithium chloride or the K-Cl distance in potassium chloride?
  - the K-O distance in potassium oxide or the Ca-O distance in calcium oxide?

a) Li-Cl vs K-Cl

The radius of the anion is the same for both compounds. So, we only need to look at the cation's radii. Potassium has a much larger ionic radius than lithium. Therefore, the K-Cl bond distance is longer than the Li-Cl bond distance.

b) K-O vs Ca-O

As in the example above, we only need to consider the cation radii. The  $K^+$  radius is larger than the  $Ca^{2+}$  radius. Therefore, the K-O bond distance is longer than the Ca-O bond distance.

10. Identify the element with the higher first ionization energy in each of the following pairs: a) iron and nickel, b) nickel and copper, c) osmium and platinum, d) nickel and palladium, e) hafnium and tantalum.

First ionization energies typically increase from left to right across a period and decrease down a group.

- Ni larger than Fe
- Cu larger than Ni
- Pt larger than Os
- Ni larger than Pd
- Ta larger than Hf

11. Write the formulas for the oxoanions of the following elements in which the element is found in its highest oxidation number. In each case, the charge of the oxoanion is given in parentheses: a) V (-3), b) Ti (-4), c) Mn (-1).

To find the highest oxidation number, please refer to slide 29 from the last lecture. In

case of an exam, these details would be provided!

(a) Vanadium (V) — charge (-3)

Highest oxidation state of vanadium: +5

Vanadium = +5

Oxygen =  $4(-2) = -8$

Total =  $+5 - 8 = -3$

Formula:  $\text{VO}_4^{3-}$  (ortho vanadate ion)

(b) Titanium (Ti) — charge (-4)

Highest oxidation state of titanium: +4

Titanium = +4

Oxygen =  $4(-2) = -8$

Total =  $+4 - 8 = -4$

Formula:  $\text{TiO}_4^{4-}$  (ortho titanate ion)

(c) Manganese (Mn) — charge (-1)

Highest oxidation state of manganese: +7

Manganese = +7

Oxygen =  $4(-2) = -8$

Total =  $+7 - 8 = -1$

Formula:  $\text{MnO}_4^-$  (permanganate ion)

Short Answers

1. a) spontaneous  
b) non-spontaneous
2. a) 17.5 kWh  
b) 2121 kWh
3. Germanium
4. Oxygen
5. Ru and Os
6. A)
7. B)
8. C)
9. D)
10. a) K–Cl is longer  
b) K–O is longer
11. a) Ni b) Cu c) Pt d) Ni e) Ta
12. a)  $\text{VO}_4^{3-}$  b)  $\text{TiO}_4^{4-}$  c)  $\text{MnO}_4^-$