This print-out should have 20 questions. Multiple-choice questions may continue on the next column or page – find all choices before answering.

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**001 10.0 points**

Which one of the processes listed below (if any) have a positive value for $\Delta S$ ?

**1.** None of the choices here have a positive $\Delta S$.

**2.** The condensation of water droplets on an ice cold drink.

**3.** The formation of ice crystals from water in a freezer compartment.

**4.** Rubbing alcohol (isopropanol) evaporating from your skin. **correct**

**Explanation:**

Evaporation is liquid to gas which has a $+\Delta S$ value. Freezing and condensation have negative values for $\Delta S$.

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**002 10.0 points**

When sodium chloride is melted, the sign of $q_{sys}$ and $\Delta S_{sys}$ are ____ and ____, respectively.

**1.** $+, -$

**2.** $-, -$

**3.** $+, +$ **correct**

**4.** $-, +$

**Explanation:**

The disorder is increased for the process. Melting is an endothermic process, therefore $q_{sys}$ will be positive.

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**003 10.0 points**

For which of the following is $\Delta S_{sys}$ likely to be greater than zero?

I. $2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$

II. $Br_2(l) \rightarrow Br_2(g)$

III. $Al(25\,°C) \rightarrow Al(80\,°C)$

**1.** III only

**2.** II, III

**3.** II only

**4.** I only

**5.** I, III

**6.** I, II, III **correct**

**Explanation:**

The entropy increases in I because two moles of gaseous reactants are converted to five moles of gaseous products. The process of vaporization always increases the entropy, thus II is correct. III is also a correct answer because the increase in temperature will always increase the entropy.

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**004 10.0 points**

A glass of cold water sits on a table top. As the day progresses, the water warms up to room temperature. For this process, $\Delta S_{surr}$ is

**1.** Positive

**2.** Negative **correct**

**3.** Zero

**Explanation:**

None

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**005 10.0 points**

Calculate the $\Delta S_{surr}$ for the following reaction at 25°C and 1 atm.

$Br_2(\ell) \rightarrow Br_2(g) \qquad \Delta H^\circ_{rxn} = +31$ kJ

**1.** +93 J/K

**2.** +124 J/K

**3.** −104 J/K **correct**

**4.** +104 J/K

**5.** −124 J/K

**6.** $-93$ J/K

**Explanation:**
In general for any process:

$$\Delta S_{\text{surr}} = \frac{-\Delta H_{\text{sys}}}{T_{\text{surr}}}$$

This is because the heat flow in the surroundings is just the opposite of the heat flow for the system ($q_{\text{surr}} = -q_{\text{sys}}$ and at constant pressure the heat is equal to $\Delta H$.

therefore $\Delta S_{\text{surr}} = -31000/298$
$= -104$ J/K

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**006 10.0 points**

The sublimation of solid carbon dioxide is a spontaneous process. Predict the sign (+, −, or 0) of $\Delta G^\circ_\text{r}$, $\Delta H^\circ_\text{r}$, and $\Delta S^\circ_\text{r}$, respectively.

**1.** −, +, + **correct**

**2.** −, −, −

**3.** −, +, −

**4.** −, 0, +

**5.** 0, +, +

**Explanation:**
$\Delta G$ is negative for a spontaneous reaction. Sublimation requires energy to facilitate the solid becoming a gas, so the process is endothermic ($\Delta H$ is positive). Finally, the entropy of a gas is more than that of a solid, so disorder increases ($\Delta S$ is positive).

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**007 10.0 points**

At constant pressure and temperature, which of the following is true about $\Delta \text{S}_{\text{surr}}$

**1.** $\Delta \text{S}_{\text{surr}} = -\Delta \text{H}_{\text{sys}}/\text{T}$ **correct**

**2.** $\Delta \text{S}_{\text{surr}} = -\Delta \text{G}_{\text{sys}}/\text{T}$

**3.** $\Delta \text{S}_{\text{surr}} = -\text{T}\Delta \text{H}_{\text{sys}}$

**4.** $\Delta \text{S}_{\text{surr}} = -\Delta \text{S}_{\text{sys}}$

**5.** $\Delta \text{S}_{\text{surr}} = -\text{T}\Delta \text{S}_{\text{sys}}$

**Explanation:**
The entropy change for the surroundings is related to the heat for the process such that

$$\Delta \text{S}_{\text{surr}} = \frac{\text{q}_{\text{surr}}}{\text{T}_{\text{surr}}} = \frac{-\text{q}}{\text{T}_{\text{surr}}}$$

where q is from the perspective of the system (out of the system into the surroundings). At a constant temperature there is only one temperature T. At constant pressure the heat for a process (from the perspective of the system) is the change in enthalpy of the system. Thus

$$\Delta \text{S}_{\text{surr}} = \frac{-\Delta \text{H}_{\text{sys}}}{\text{T}}$$

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**008 10.0 points**

Consider a chemical reaction where $\Delta S$ is 36.1 J/mol K, and $\Delta H$ is -2.88 kJ/mol. What is the change in entropy for the universe ($\Delta S_{\text{univ}}$) for this reaction at 50°C?

**1.** +40.5 J/mol K

**2.** +27.2 J/mol K

**3.** -47.9 J/mol K

**4.** +45.0 J/mol K **correct**

**5.** -36.1 J/mol K

**Explanation:**
The heat leaving the system enters the surroundings. Therefore
$\Delta S_{\text{surr}} = -\Delta H/T$
$\Delta S_{\text{surr}} = -(-2880)/323.15$
$\Delta S_{\text{surr}} = +8.91$ J/mol K
Now $\Delta S_{\text{univ}}$ can be easily calculated:
$\Delta S_{\text{univ}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}}$
$\Delta S_{\text{univ}} = 36.1 + 8.91 = 45.0$ J/mol K

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**009 10.0 points**

Calculate $\Delta G^\circ$ for the following reaction at 298 K.

$$NH_4NO_3(s) \rightarrow N_2O(g) + 2H_2O(g)$$

**1.** +130 kJ

**2.** $-1.33 \times 10^5$ kJ

**3.** $+169$ kJ

**4.** $-113$ kJ

**5.** $+97.2$ kJ

**6.** $-169$ kJ **correct**

**7.** $-130$ kJ

**Explanation:**

Must use $\Delta H_\text{f}^\circ$ and $S^\circ$ values because the $\Delta G_\text{f}^\circ$ ones are not available. Then to get free energy change use:

$$\Delta G = \Delta H - T\Delta S$$

$\Delta S = [220 + 2(189)] - 151 = 447$ J/K
$\Delta H = [82 + 2(-242)] - (-366) = -36$ kJ
$\Delta G = -36000 - 298(447) = -169206$ J
$\Delta G = -169$ kJ

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**010 10.0 points**

For a given reaction, if $\Delta H^\circ_\text{rxn}$ is (negative/positive/either) and $\Delta S^\circ_\text{rxn}$ is (negative/positive/either), then the value of $\Delta G^\circ_\text{rxn}$ will always be negative, regardless of the temperature.

**1.** positive, negative

**2.** negative, positive **correct**

**3.** positive, either

**4.** negative, either

**5.** either, positive

**6.** either, negative

**Explanation:**

This comes from

$$\Delta G = \Delta H - T\Delta S\,.$$

In order for $\Delta G^\circ_\text{rxn}$ to always be negative, $\Delta H^\circ_\text{rxn}$ must always be negative and $\Delta S^\circ_\text{rxn}$ must always be positive.

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**011 10.0 points**

What is the change in entropy ($\Delta S$) for the heating of 20.0 grams of methanol ($CH_3OH$, liquid) from 34°C to 62°C?

**1.** 0 J/K

**2.** 0.22 J/K

**3.** -30.42 J/K

**4.** 1418 J/K

**5.** 30.42 J/K

**6.** 168.81 J/K

**7.** 4.42 J/K **correct**

**Explanation:**

The specific heat capacity of methanol is equal to 2.533J/g°C via table of data. Use the equation:

$$\Delta S = m\, C_\text{s} \ln\left(\frac{T_2}{T_1}\right)$$

$\Delta S = 20(2.533)\ln(335/307) = 4.42$

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**012 10.0 points**

A 15 g sample of steam at 110 °C was placed into a warehouse freezer at $-40$ °C. In order to properly calculate the total change in entropy of this system, what equations would you use?

I. $\Delta \text{S} = \text{nC}\ln\left(\frac{\text{T}_\text{f}}{\text{T}_\text{i}}\right)$

II. $\Delta \text{S} = \frac{\Delta \text{H}}{\text{T}}$

III. $\Delta \text{S}_\text{univ} = \Delta \text{S}_\text{sys} + \Delta \text{S}_\text{surr}$

IV. $\Delta \text{S} = \text{mC}\Delta \text{T}$

**1.** I, II, III, IV

**2.** I, III

**3.** II, IV

**4.** I, II **correct**

**5.** IV

**Explanation:**
Equation I is used three times (cooling the steam from 110 to 100 °C, cooling the water from 100 to 0 °C, and cooling the ice from 0 to −40 °C). Equation II would be used two times (condensing the steam and freezing the water).

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**013 10.0 points**

Iron metal will react with oxygen gas to form a variety of iron oxides. This oxidation reaction is typically referred to as the iron "rusting". The fact that this reaction is spontaneous at room temperature tells you that

**1.** the 2nd law of thermodynamics has been violated

**2.** iron oxides have a higher standard entropy compared to oxygen and iron

**3.** iron oxides have a positive enthalpy of formation

**4.** iron oxides have a negative Gibbs energy of formation **correct**

**Explanation:**
The fact that the iron and oxygen (both elements) spontaneously form a compound, iron oxide, at room temperature tell us that the free energy of formation of the iron oxide must be negative. The iron oxide is lower in free energy compared to the elements that it is formed from.

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**014 10.0 points**

The absolute entropy of a system ($S$ measured in J/K) is related to the number of microstates in that system. Consider the three processes listed below. Which one(s) will result in an increase in the number of microstates in the system?

I) The temperature of a gas is raised by 3°C.

II) A fixed amount of gas is allowed to expand to a slightly larger volume.

III) The total number of gas molecules in a system is reduced to a smaller number.

**1.** II and III only

**2.** I and III only

**3.** I and II only **correct**

**4.** III only

**5.** I only

**6.** II only

**7.** I, II, and III

**Explanation:**
Raising the temperature will always add to the number of available energy states in a system. More volume allows more states as well. Reducing the number of molecules however, will lower the number of microstates.

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**015 10.0 points**

The oxidation of sugar to carbon dioxide and water is a spontaneous chemical reaction. Since we know that reactions that occur spontaneously in one direction cannot occur spontaneously in the reverse direction, how can we understand photosynthesis?

**1.** It is not a spontaneous chemical reaction; it is driven by an external source of energy – light. **correct**

**2.** This reaction is characterized by an energy change so close to zero that it is essentially reversible.

**3.** Thermodynamics deals only with closed systems; photosynthesis is an open system.

**4.** Thermodynamics does not apply to photochemical reactions.

**5.** Thermodynamics does not apply to living systems.

**Explanation:**

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**016 10.0 points**

The conditions for a specific exothermic reaction are such that it is currently non-spontaneous. Which of the following changes to the conditions will likely make the reaction spontaneous?

**1.** increase the temperature

**2.** the reaction spontaneity, in this case, cannot be changed with temperature

**3.** decrease the temperature **correct**

**Explanation:**

The fact that an exothermic reaction $(-\Delta H)$ is non-spontaneous means that the entropy change is negative $(-\Delta S)$ and is at a high enough temperature that the reaction is governed by the entropy term in the equation $\Delta G = \Delta H - T\Delta S$.

Decreasing the temperature will eventually make the entropy term smaller in magnitude than the enthalpy term and the resulting $\Delta G$ will go negative and therefore be spontaneous.

**017 10.0 points**

A particular protein folds spontaneously at 25 °C and 1 atm. During this folding, the protein changes conformation from a higher entropy unfolded state to a lower entropy folded state. For this process, ΔH is

**1.** No way to know

**2.** $\Delta$H $< 0$ **correct**

**3.** $\Delta$H $= 0$

**4.** $\Delta$H $> 0$

**Explanation:**

If the reaction proceeds spontaneously, then ΔG must be negative. The reaction also transitions from a higher entropy state to a lower entropy state, resulting in a negative ΔS. Using the Gibbs' Free Energy Equation, ΔH must be negative in order to have both a negative ΔG and a negative ΔS.

**018 10.0 points**

Calculate the entropy of vaporization for compound X at its boiling point of 138°C. The enthalpy of vaporization of compound X is 42.2 kJ/mol.

1. 114.168
2. 109.365
3. 61.3854
4. 96.5584
5. 92.3661
6. 76.0959
7. 79.1469
8. 76.8945
9. 102.639
10. 81.7896

Correct answer: 102.639 J/molK.

**Explanation:**

$T = 138°\text{C} + 273.15 = 411.15$ K
$\Delta H = 42.2$ kJ/mol $= 42200$ J/mol

$$\Delta S = \frac{\Delta H}{T} = \frac{42200 \text{ J/mol}}{411.15 \text{ K}} = 102.639 \text{ J/molK}$$

**019 10.0 points**

Which of the following have standard Gibbs free energy of formation values equal to zero?

$N_2$(g) $O_2(\ell)$ Ar($\ell$) $CO_2$(g) He(g)

**1.** $N_2$(g) and He(g) **correct**

**2.** Ar($\ell$) and He(g)

**3.** $N_2$(g), $CO_2$(g), and He(g)

**4.** $N_2$(g), $O_2(\ell)$, Ar($\ell$) , and He(g)

**5.** $O_2(\ell)$ and Ar($\ell$)

**Explanation:**

Standard state for all of these should be gas state. $CO_2$ is not an element. Only elements in their standard states will have $\Delta G_f^\circ$ equal to zero. Only $N_2$(g) and He(g) match this criteria.

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**020 10.0 points**

When water condenses, what are the signs for $q$, $w$, and $\Delta S_{sys}$, respectively?

**1.** $+, +, -$

**2.** $-, +, -$ **correct**

**3.** $+, -, +$

**4.** $+, -, -$

**5.** $+, +, +$

**6.** $-, +, +$

**Explanation:**