College Admission

ACS-General-Chemistry
ACS General Chemistry Certification Exam

Latest Version: 6.0

Question: 1

Which of the following equations represents the balanced chemical reaction between Mg_3N_2 and H_2O?

A. $Mg_3N_2(s) + 6\ H_2O(l) \rightarrow 3\ Mg(OH)_2(s) + 2\ NH_3(g)$
B. $Mg_3N_2(s) + 3\ H_2O(l) \rightarrow 3\ Mg(OH)_2(s) + 2\ NH_3(g)$
C. $2\ Mg_3N_2(s) + 3\ H_2O(l) \rightarrow 6\ Mg(OH)_2(s) + 2\ NH_3(g)$
D. $Mg_3N_2(s) + H_2O(l) \rightarrow 3\ Mg(OH)_2(s) + 2\ NH_3(g)$

Answer: A

Explanation:

The unbalanced form for this chemical equation is:

$$Mg_3N_2(s) + H_2O(l) \rightarrow Mg(OH)_2(s) + NH_3(g)$$

There are 3 Mg atoms and 2 N atoms on the reactant side, so the number of $Mg(OH)_2$ molecules needs to be multiplied by 3 and number of NH_3 molecules needs to be multiplied by 2:

$$Mg_3N_2(s) + H_2O(l) \rightarrow 3\ Mg(OH)_2(s) + 2\ NH_3(g)$$

Next, balance the number of H atoms. There are $3 \times 2 + 2 \times 3 = 12$ H atoms on the product side, so multiply the number of water molecules on the reactant side by 6:

$$Mg_3N_2(s) + 6\ H_2O(l) \rightarrow 3\ Mg(OH)_2(s) + 2\ NH_3(g)$$

Lastly, check the number of O atoms. There are 6 O atoms on the reactant side, and $3 \times (1 \times 2) = 6$ O atoms on the product side, which means that the number of O atoms is balanced. The reaction is balanced.

Question: 2

An object with a mass of 3.70 g is heated to 85.0 °C in an oven. It is then removed from the oven and placed in a container with exactly 200.0 g of water at 19.0 °C. The object increased the water temperature by 0.810 °C. What is the specific heat capacity of this object? (The specific heat capacity for water is 4.18 J/(g · K).)

A. 9.24 J/(g.K)
B. 225 J/(g.K)
C. 2.75 J/(g.K)
D. 2.80 J/(g.K)

Answer: D

Explanation:

The object absorbed heat in the oven then released heat to the water in the container. Using the equation below, calculate the amount of heat being released to the water, as the mass, specific heat capacity, and change in temperature of the water in the container are known. (Since the increments of kelvin and degrees Celsius are equivalent, they can be used interchangeably for the units of change in temperature: $\Delta T = 0.810\ °\text{C} = 0.810\ \text{K}$.)

$$q = C_s \times m \times \Delta T$$

$$q = (4.18\ \text{J}/(\text{g}\cdot\text{K}))(200.0\ \text{g})(0.810\ \text{K}) = 677.16\ \text{J}$$

The amount of heat that the water absorbed is equal to the amount of heat released by the object. The final temperature for the water and the object should be the same. The final temperature for the water is $0.810\ °\text{C} + 19.0\ °\text{C} = 19.81\ °\text{C}$. This means the absolute value of the temperature change for the object is $(85.0 - 19.81)\ °\text{C} = 65.19\ °\text{C}$.

Apply the specific heat equation for the object and solve for C_s:

$$677.16\ \text{J} = C_s \times (3.70\ \text{g}) \times 65.19\ \text{K}$$

$$C_s = 2.80\ \text{J}/(\text{g}\cdot\text{K})$$

Question: 3

Consider the following two-step reaction mechanism:

Step 1: $NO(g) + Cl_2(g) \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} NOCl_2(g)$

Step 2: $NOCl_2(g) + NO(g) \xrightarrow{k_2} 2\ NOCl(g)$

Overall: $2\ NO(g) + Cl_2(g) \longrightarrow 2\ NOCl(g)$

If Step 1 is fast and has a rate constant of k_1 in the forward reaction (the rate constant of the reverse reaction is k_{-1}), while Step 2 is slow and has a rate constant of k_2, what is the rate law of the overall reaction?

A. $\frac{k_1}{k_2 k_{-1}}[NO][Cl_2]$

B. $\frac{k_1}{k_2 k_{-1}}[NO]^2[Cl_2]$

C. $\frac{k_1 k_2}{k_{-1}}[NO][Cl_2]$

D. $\frac{k_1 k_2}{k_{-1}}[NO]^2[Cl_2]$

Answer: D

Explanation:

Since Step 2 is the rate-determining step, the rate law of the reaction is dependent on this step. The rate law should be written as:

$$Rate = k_2[NOCl_2][NO]$$

However, $NOCl_2$ is an intermediate that is produced in step 1 and soon consumed in Step 2. Its concentration is difficult to measure, so it is the best to write the rate law in terms of the species whose concentrations can be measured easily. The Step 1 is fast and at equilibrium, which means its rates for the forward and reverse reaction are the same:

$$Rate = k_1[NO][Cl_2] = k_{-1}[NOCl_2]$$

Rearrange the rate law above and write the concentration of $NOCl_2$ in terms of the concentration of NO and Cl_2. Both NO and Cl_2 are reactants, so their concentrations are easy to measure:

$$[NOCl_2] = \frac{k_1}{k_{-1}}[NO][Cl_2]$$

Substitute the above expression into the rate law for Step 2 to get the rate law as:

$$Rate = k_2[NOCl_2][NO] = k_2\left(\frac{k_1}{k_{-1}}[NO][Cl_2]\right)[NO] = \frac{k_1k_2}{k_{-1}}[NO]^2[Cl_2]$$

Question: 4

Iron(III) oxide (Fe_2O_3) dissolves in dilute HCl solution:

$$Fe_2O_3(s) + 6\,HCl(aq) \rightarrow 2\,FeCl_3(aq) + 3\,H_2O(l)$$

75.0 mL HCl solution of 0.325 M is added to 0.432 g Fe_2O_3. Which one is the limiting reactant in this case, and how much more of the limiting reactant is needed to fully react with the excess reactant?

A. Fe_2O_3, 0.0135 g
B. Fe_2O_3, 0.217 g
C. HCl, 5.00 mL
D. HCl, 25.00 mL

Answer: B

Explanation:

To determine which reactant is the limiting reactant, convert their amounts to number of moles, then compare the numbers with the molar ratio that is indicated by the stoichiometric coefficients in the equation. The amount of HCl is:

$$M \times V = (0.325\ \mathrm{M})(75.0\ \mathrm{mL}) = \left(0.325\ \frac{\mathrm{mol}}{\mathrm{L}}\right)(75.0\ \mathrm{mL})\left(\frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}\right) = 0.0244\ \mathrm{mol}$$

The amount of Fe_2O_3 is:

$$(0.432\ \mathrm{g})\left(\frac{1\ \mathrm{mol}}{159.7\ \mathrm{g}}\right) = 2.71 \times 10^{-3}\ \mathrm{mol}$$

In the balanced chemical equation, the molar ratio between Fe_2O_3 and HCl is 1:6. The molar ratio of the actual amount of Fe_2O_3 to HCl is:

$$(2.71 \times 10^{-3}) : (0.0244) = 1 : 8.99$$

So HCl is in excess. Therefore, Fe_2O_3 is the limiting reactant. To fully consume the excess HCl, the amount of Fe_2O_3 needed is:

$$\frac{0.0244\ \mathrm{mol}}{6} = 4.06 \times 10^{-3}\ \mathrm{mol}$$

The amount of additional Fe_2O_3 needed to add into the reaction is:

$$(4.06 \times 10^{-3} - 2.71 \times 10^{-3})\ \mathrm{mol} = 1.35 \times 10^{-3}\ \mathrm{mol}$$

The mass of this portion of Fe_2O_3 is:

$$(1.35 \times 10^{-3}\ \mathrm{mol})(159.7\ \mathrm{g/mol}) = 0.217\ \mathrm{g}$$

Question: 5

Which of the following pairs of isotopes belong to the same element?

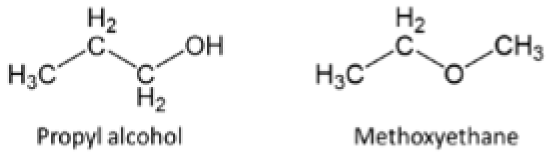
A. ${}^{78}_{34}X$ and ${}^{82}_{34}X$
B. ${}^{82}_{34}X$ and ${}^{82}_{36}X$
C. ${}^{78}_{34}X$ and ${}^{78}_{36}X$
D. ${}^{78}_{34}X$ and ${}^{76}_{32}X$

Answer: A

Explanation:
The isotopes of the same element all have the same atomic number (the same number of protons). They can vary in their number of neutrons and atomic mass. The only pair of isotopes that this criteria are the ones in choice A. Other pairs may have the same atomic mass or number of neutrons, but not the same atomic number, which means that they are different elements.

Question: 6

Methoxyethane and propyl alcohol both have the chemical formula of C_3H_8O. Methoxyethane has a boiling point of 7.4 °C, but propyl alcohol has a boiling point of 97.2 °C. What intermolecular forces contribute to such a difference in their boiling points?



A. Hydrogen bonding
B. Dipole-dipole interactions
C. London dispersion forces
D. Ion-dipole interactions

Answer: A

Explanation:
Since the chemical formulae of both compounds are the same, their molecular weights are also the same. They both experience dipole-dipole interactions and London dispersion forces, but there is no ionic species involved in neither of them, so the ion-dipole interactions do not apply. London dispersion forces largely depend on the polarizability the molecules, which is mainly affected by molecular weight. As they have the same molecular weight, the differences in the dispersion forces they experience are not likely to affect their boiling points. Propyl alcohol is more polar than methoxyethane and has a hydroxy functional group (—0H) which is subject to hydrogen bonding. The propyl alcohol experiences greater dipole-dipole interactions than the methoxyethane, but the magnitude of hydrogen bonding is typically much greater than that of the dipole-dipole interactions. As a result, the extra sets of hydrogen bonding in propyl alcohol raise its boiling point.

Question: 7

Consider again the reaction of oxidizing NO with O_2:

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

Both the NO and O_2 are colorless, while the NO_2 is reddish-brown in color. If the pressure of the reaction is increased by reducing the volume of the reaction flask, in which direction is the equilibrium going to shift and is the reaction mixture going to become lighter or darker in color?

A. Equilibrium shifts to the right, and the mixture becomes darker.
B. Equilibrium shifts to the right, and the mixture becomes lighter.
C. Equilibrium shifts to the left, and the mixture becomes darker.
D. Equilibrium shifts to the left, and the mixture becomes lighter.

Answer:

Explanation:
The given reaction has a larger total number of gas molecules on the reactant side than the product side. If the pressure of the reaction is increased by decreasing the volume, the equilibrium is going to shift to the direction with a smaller number of gas molecules, which is the product side to the right). Since the equilibrium is shifted to the product side, there are more NO: molecules than before. Therefore, the reaction mixture is going to appear darker in color.

Question: 8

A saturated solution of calcium sulfate $(CaSO_4)$ contains 0.525 g $CaSO_4$ in 2.50 L water. What is the solubility product (K_{sp}) of $CaSO_4$?

A. 3.65×10^{-9}
B. 2.38×10^{-6}
C. 1.49×10^{-5}
D. 1.54×10^{-3}

Answer: B

Explanation:
The solubility of $CaSO_4$ in mol/L (in other words, M) is:

$$[Ca^{2+}] = [SO_4{}^{2-}] = \left(\frac{0.525\ g}{2.50\ L}\right)\left(\frac{1.00\ mol}{136.14\ g}\right) = 1.54 \times 10^{-3}\ mol/L$$

The dissociation process for $CaSO_4$ in water is:

$$CaSO_4(s) \rightleftharpoons Ca^{2+}(aq) + SO_4{}^{2-}(aq)$$

The K_{sp} for $CaSO_4$ is written as:

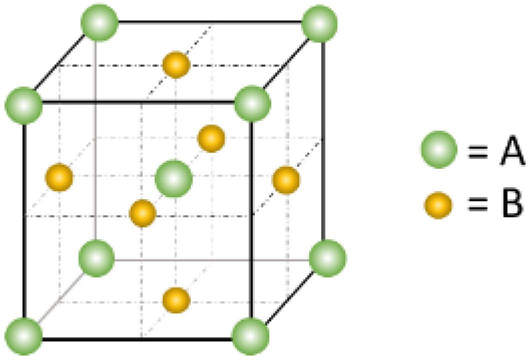
$$K_{sp} = [Ca^{2+}][SO_4^{2-}]$$

Substituting the values of Ca^{2+} and$SO_4{}^{2-}$ concentrations yields:

$$K_{sp} = [Ca^{2+}][SO_4{}^{2-}] = (1.54 \times 10^{-3})(1.54 \times 10^{-3}) = 2.38 \times 10^{-6}$$

Question: 9

A compound that is composed of elements A and B adopts the following unit cell structure in its crystals:

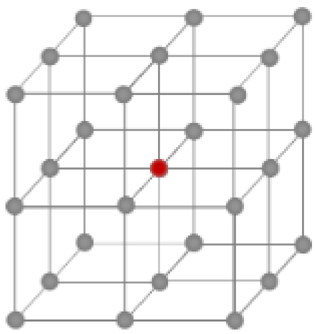


How many A and B atoms are there in each unit cell?

A.9 and 6
B.5 and 3
C.3 and 2
D.2 and 3

Answer: D

Explanation:
The unit cell is a combination of face- and body-centered cubic packing. For the A atoms in this unit cell, there are 8 on the corners and 1 in the center of the cell. For the 8 corner atoms, each of them is shared among a total of 8 unit cells (as illustrated for the central atom below), so the atom count of the corner atoms is: $8 \times \frac{1}{8} = 1$. The atom in the center of the cubic cell is not shared with any other unit cells. Therefore, the atom count for A is: $1 + 8 \times \frac{1}{8} = 2$.



As for the B atoms, there are 6 on the center of each face in the unit cell. Each of these atoms is shared between 2 unit cells, so the atom count for B is: $6 \times \frac{1}{2} = 3$.

Question: 10

In the n = 4 electron shell of an atom, how many subshells and orbitals are present?

A.4 subshells, 16 orbitals
B.3 subshells, 16 orbitals

C.4 subshells, 9 orbitals
D.3 subshells, 9 orbitals

Answer: B

Explanation:

When $n = 4$ for a shell of electrons, there are 4 possible values for the angular momentum quantum number l: 0, 1, 2, and 3. Each value corresponds to a subshell of electrons, so there are 4 subshells with this value of principle quantum number. The number of orbitals for each subshell can be summarized in the table below:

Values of l	Subshell Designation	Values of m_l	Number of Orbitals
0	$4s$	0	1
1	$4p$	$-1,0,1$	3
2	$4d$	$-2,-1,0,1,2$	5
3	$4f$	$-3,-2,-1,0,1,2,3$	7

By adding the number of orbitals in each subshell, the total number of orbitals in this shell of electrons is 16.

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