

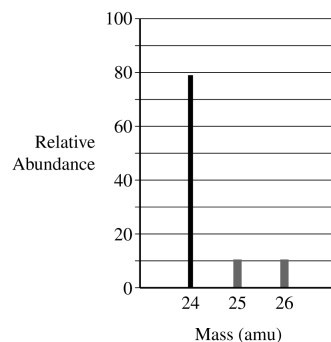
Question 1: Long Answer

10 points

A (i) For the correct plotted lines:

Point 01

The abundance for the two lines should be between 10 and 11.



(ii) For the correct answer:

Point 02

Magnesium-26 has one more neutron than magnesium-25 does.

B (i) For a correct explanation:

Point 03

The charge on the sodium ion is less than the charge on the magnesium ion. A smaller charge results in a weaker Coulombic attraction between Na^+ and water.

(ii) For a correct explanation:

Point 04

The Na^+ ion is larger than the Mg^{2+} ion, so the distance between the Na^+ and the oxygen on the water molecule will be greater. As distance increases, Coulombic attraction decreases.

C For the correct calculated value:

Point 05

$$\text{pOH} = -\log(2.80 \times 10^{-4}) = 3.553$$

$$\text{pH} = 14 - \text{pOH} = 14 - 3.553 = 10.447$$

D For the correct calculated value:

Point 06

$$M_1V_1 = M_2V_2$$

$$M_2 = \frac{(1.85 \times 10^{-3} M)(0.03500 \text{ L})}{(0.03500 \text{ L} + 0.05000 \text{ L})} = 7.62 \times 10^{-4} M$$

E (i) For the correct expression:

Point 07

$$K_{sp} = [\text{Mg}^{2+}][\text{OH}^-]^2$$

(ii) For the correct calculated value, consistent with part D and part E (i):

Point 08

$$Q = [\text{Mg}^{2+}][\text{OH}^-]^2 = (7.62 \times 10^{-4})(1.65 \times 10^{-4})^2 = 2.07 \times 10^{-11}$$

(iii) For the correct prediction and justification, consistent with part E (ii).

Point 09

Examples of acceptable responses may include the following:

- $Q > K_{sp}$, so a precipitate will form.
- The concentration of the ions in solution (represented by Q) is greater than that of a saturated solution, so a precipitate will form.

F For the correct answer and justification:

Point 10

Decrease. The H^+ from $\text{HNO}_3(aq)$ will react with OH^- , decreasing $[\text{OH}^-]$ and causing $Q < K_{sp}$. As a result, more $\text{Mg}(\text{OH})_2(s)$ will dissolve until equilibrium is reestablished, resulting in less $\text{Mg}(\text{OH})_2(s)$.

Question 2: Long Answer

10 points

A (i) For the correct calculated value: **Point 01**

$$2.883 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = 0.1600 \text{ mol H}_2\text{O}$$

(ii) For the correct calculated number of moles of H (may be implicit): **Point 02**

$$0.1600 \text{ mol H}_2\text{O} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 0.3200 \text{ mol H}$$

For the correct empirical formula. **Point 03**

Examples of acceptable responses may include the following:

- $x : y : z = (\text{moles of C}) : (\text{moles of H}) : (\text{moles of O})$
 $x : y : z = 0.2400 : 0.3200 : 0.2400 = 3 : 4 : 3$
Therefore, the empirical formula of ascorbic acid is C₃H₄O₃.

- $0.2400 \text{ mol CO}_2 \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.2400 \text{ mol C}$

$$\frac{0.3200 \text{ mol H}}{0.2400 \text{ mol C}} = \frac{4 \text{ H}}{3 \text{ C}}$$

Given that the ratio of C:O is 1:1, the empirical formula of ascorbic acid is C₃H₄O₃.

B (i) For the correct calculated value: **Point 04**

$$0.0160 \text{ L NaOH} \times \frac{0.0550 \text{ mol NaOH}}{1 \text{ L NaOH}} \times \frac{1 \text{ mol HAsc}}{1 \text{ mol NaOH}} = 8.80 \times 10^{-4} \text{ mol HAsc}$$

$$\frac{8.80 \times 10^{-4} \text{ mol HAsc}}{0.0100 \text{ L}} = 0.0880 \text{ M HAsc}$$

(ii) For the correct $\text{p}K_a$: **Point 05**

4.1 (acceptable range: 4.0–4.3)

(iii) For the correct ratio, consistent with part B (ii): **Point 06**

Using the Henderson-Hasselbalch equation:

$$\text{pH} = \text{p}K_a + \log \left(\frac{[\text{Asc}^-]}{[\text{HAsc}]} \right)$$

$$4.7 = 4.1 + \log \left(\frac{[\text{Asc}^-]}{[\text{HAsc}]} \right)$$

$$\frac{[\text{Asc}^-]}{[\text{HAsc}]} = 10^{0.6} = 4.0$$

C (i) For a correct explanation. **Point 07**

Examples of acceptable responses may include the following:

- $\frac{4.914 \times 10^{-4}}{2.457 \times 10^{-4}} = \left(\frac{0.900}{0.450} \right)^a$, thus $a = 1$
- Comparing trials 1 and 3, the rate doubles when the concentration of ascorbic acid is doubled and the triiodide ion concentration is constant, indicating that the process is first order with respect to ascorbic acid.*

(ii) For the correct calculated value: **Point 08**

$$\text{rate} = k[\text{HAsc}][\text{I}_3^-]$$

Using trial 1 data:

$$k = \frac{\text{rate}}{[\text{HAsc}][\text{I}_3^-]} = \frac{2.457 \times 10^{-4} \text{ M/s}}{(0.450 \text{ M})(1.200 \text{ M})} = 4.55 \times 10^{-4} \text{ M}^{-1} \text{ s}^{-1}$$

For the correct units: **Point 09**

$$\text{M}^{-1} \text{ s}^{-1}$$

D For the correct answer: **Point 10**

Ion-dipole attractions are present between I₃[−] ions and water but not between I₂ molecules and water.

Question 3: Long Answer

10 points

A For the correct diagram:

Point 01

B (i) For a correct explanation:

Point 02

Because gas particles are more dispersed (have more microstates) than solids, the entropy decreases as the reactants (which include a gas) convert to the solid product.

(ii) For the correct answer and a valid justification:

Point 03

Yes. Given that $\Delta G_{rxn}^\circ = \Delta H_{rxn}^\circ - T\Delta S_{rxn}^\circ$, the reaction must have $\Delta G_{rxn}^\circ < 0$ to be favorable. Because the reaction is exothermic, $\Delta H_{rxn}^\circ < 0$ and enthalpy contributes to favorability. $\Delta S_{rxn}^\circ < 0$, so entropy does not contribute to favorability.

C (i) For the correct calculated value reported with the correct number of significant figures:

Point 04

$$q = mc\Delta T = (100.1 \text{ g})(4.18 \text{ J/(g}\cdot^\circ\text{C)})(22.38^\circ\text{C} - 22.00^\circ\text{C})$$

$$q = 160 \text{ J} = 0.16 \text{ kJ}$$

(ii) For the correct calculated value, consistent with part C (i):

Point 05

$$q_{rxn} = -q_{surr} = -0.16 \text{ kJ}$$

$$\Delta H_{rxn}^\circ = \frac{-0.16 \text{ kJ}}{0.100 \text{ g P}_4\text{O}_{10}} \times \frac{283.9 \text{ g P}_4\text{O}_{10}}{1 \text{ mol P}_4\text{O}_{10}} \times \frac{1 \text{ mol P}_4\text{O}_{10}}{1 \text{ mol}_{rxn}} = -450 \text{ kJ/mol}_{rxn}$$

For the correct sign:

Point 06

$$-450 \text{ kJ/mol}_{rxn}$$

D For the correct answer and a valid justification:

Point 07

Less than. If less P_4O_{10} is present, less thermal energy will be transferred to the water during the reaction, causing the temperature increase to be less than it was with 0.100 g of P_4O_{10} .

E For the correct calculated value:

Point 08

Using Hess's law:

$$\Delta H_{f, \text{PCl}_5(\text{g})}^\circ = \frac{1}{4}\Delta H_1^\circ + \Delta H_2^\circ$$

$$\Delta H_{f, \text{PCl}_5(\text{g})}^\circ = \frac{1}{4}(-1148) + (-88) = -375 \text{ kJ/mol}$$

F (i) For the correct calculated value:

Point 09

$$K_p = \frac{P_{\text{PCl}_5}}{(P_{\text{PCl}_3})(P_{\text{Cl}_2})} = \frac{4.00}{(2.00)(6.00)} = \frac{1}{3} = 0.333$$

(ii) For the correct answer and a valid justification:

Point 10

Decrease. The negative value of ΔH_2° indicates that the reaction is exothermic. Because exothermic reactions favor reactant formation at higher temperature, the value of K_p decreases.

4 points

Question 4: Short Answer

A For the correct answer:

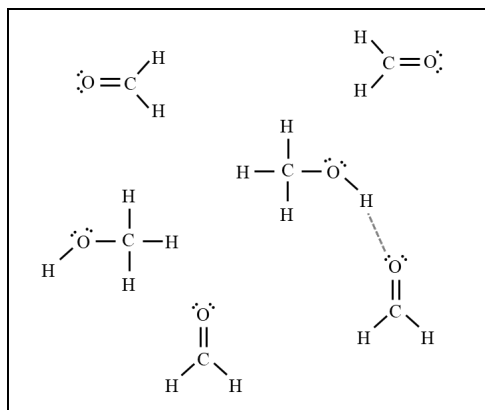
Point 01

 sp^2

B For a correct diagram:

Point 02

The diagram should show a dashed line between the O atom in one H_2CO molecule and the H atom in the $-\text{OH}$ group of one CH_3OH molecule. See example response below.



C (i) For a correct proposal:

Point 03

The proposed temperature should be in the range 181 K–254 K.

(ii) For the correct calculated value:

Point 04

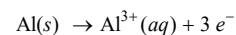
$$8.59 \text{ g CH}_3\text{OH} \times \frac{1 \text{ mol CH}_3\text{OH}}{32.04 \text{ g CH}_3\text{OH}} \times \frac{-37.6 \text{ kJ}}{1 \text{ mol CH}_3\text{OH}} = -10.1 \text{ kJ}, \text{ so } 10.1 \text{ kJ are removed.}$$

Question 6: Short Answer

4 points

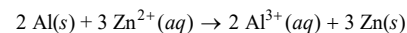
A For the correct equation (state symbols not required):

Point 01



B For the correct balanced net ionic equation (state symbols not required):

Point 02



C For the correct answer and a valid justification that correctly compares the masses of Al and Zn based on their molar masses and the stoichiometry of the balanced equation.

Point 03

Examples of acceptable responses may include the following:

- Zn experiences a greater change in mass. Assuming the entire Al anode reacts:

$$50.0 \text{ g Al} \times \frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \times \frac{3 \text{ mol Zn}}{2 \text{ mol Al}} \times \frac{65.38 \text{ g Zn}}{1 \text{ mol Zn}} = 182 \text{ g Zn}$$

- Zn experiences a greater change in mass.

$$1 \text{ mol}_{\text{rxn}} \times \frac{3 \text{ mol Zn}}{1 \text{ mol}_{\text{rxn}}} \times \frac{65.38 \text{ g Zn}}{1 \text{ mol Zn}} = 196.1 \text{ g Zn}$$

$$1 \text{ mol}_{\text{rxn}} \times \frac{2 \text{ mol Al}}{1 \text{ mol}_{\text{rxn}}} \times \frac{26.98 \text{ g Al}}{1 \text{ mol Al}} = 53.96 \text{ g Al}$$

Thus, for however many moles of reaction that proceed, the mass of Zn produced will be greater than the mass of Al consumed.

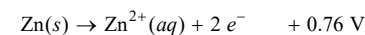
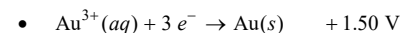
- Zn experiences a greater change in mass. As the reaction proceeds, three moles of Zn are used for every two moles of Al. Thus, for every 196 g of Zn that are produced, 54 g of Al are consumed.

D For the correct calculated value.

Point 04

Examples of acceptable responses may include the following:

$$E_{\text{cell}}^\circ = 1.50 \text{ V} + 0.76 \text{ V} = 2.26 \text{ V}$$



$$E_{\text{cell}}^\circ = 2.26 \text{ V}$$

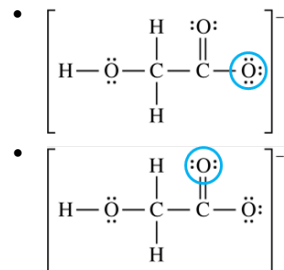
Question 7: Short Answer

4 points

A For a correct circled atom.

Point 01

Accept one of the following:



(Because of resonance, the two C–O bonds on the right are equivalent.)

B (i) For the correct calculated value:

Point 02

$$K_b = \frac{[\text{HC}_2\text{H}_3\text{O}_3][\text{OH}^-]}{[\text{C}_2\text{H}_3\text{O}_3^-]} = \frac{(1.3 \times 10^{-5})(1.3 \times 10^{-5})}{(2.5 - 1.3 \times 10^{-5})} \approx \frac{(1.3 \times 10^{-5})^2}{(2.5)} = 6.8 \times 10^{-11}$$

(ii) For the correct calculated value, consistent with part B (i):

Point 03

$$K_a = \frac{K_w}{K_b} = \frac{1.0 \times 10^{-14}}{6.8 \times 10^{-11}} = 1.5 \times 10^{-4}$$

C For the correct answer and a valid justification:

Point 04

Agree. H_3O^+ is consumed in step 1 and regenerated in step 2, which is consistent with the behavior of a catalyst.