Begin your response to **QUESTION 1** on this page.

CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

For each question, show your work for each part in the space provided after that part. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

1. Answer the following questions related to manganese compounds.

(a) Manganese has several common oxidation states.

(i) Write the complete electron configuration for an Mn atom in the ground state.

(ii) When manganese forms cations, electrons are lost from which subshell first? Identify both the number and letter associated with the subshell.

A student performs an experiment to produce a manganese salt of unknown composition, $Mn_xCl_y(aq)$, and determine its empirical formula. The student places a sample of $Mn(s)$ in a beaker containing excess $HCl(aq)$, as represented by the following equation.

$$x\ Mn(s) + y\ HCl(aq) \rightarrow Mn_xCl_y(aq) + \frac{y}{2}H_2(g)$$

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

The student heats the resulting mixture until only $Mn_xCl_y(s)$ remains in the beaker. The data are given in the following table.

Mass of empty beaker	60.169 g
Mass of beaker and $Mn(s)$	61.262 g
Mass of beaker and Mn_xCl_y after heating to constant mass	62.673 g

(b) Calculate the mass of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

(c) Calculate the number of moles of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

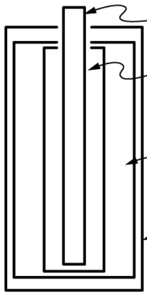
(d) The student determines that 0.0199 mol of Mn was used in the experiment. Use the data to determine the empirical formula of the $Mn_xCl_y(s)$.

(e) The student repeats the experiment using the same amounts of Mn and HCl and notices that some of the Mn_xCl_y splatters out of the beaker as it is heated to dryness. Will the number of moles of Cl calculated for this trial be greater than, less than, or equal to the number calculated in part (c) ? Justify your answer.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

(f) Another compound of manganese, MnO_2, is used in alkaline batteries, represented by the following diagram. Some half-reactions are given in the table.



Reduction Half-Reaction	$E°$ (V)
$Zn^{2+}(aq) + 2\,e^- \rightarrow Zn(s)$	–0.76
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	–1.28
$2\,MnO_2(s) + H_2O(l) + 2\,e^- \rightarrow Mn_2O_3(s) + 2\,OH^-(aq)$	0.15

(i) Based on the half-reactions given in the table, write the balanced net ionic equation for the reaction that has the greatest thermodynamic favorability.

(ii) Calculate the value of E°_{cell} for the overall reaction.

(iii) Calculate the value of $\Delta G°$ in kJ/mol$_{rxn}$.

(iv) A student claims that the total mass of an alkaline battery decreases as the battery operates because the anode loses mass. Do you agree with the student's claim? Justify your answer.

GO ON TO THE NEXT PAGE.

Question 1: Long Answer — 10 points

(a) (i)	For the correct answer: Accept one of the following: • $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$ • $[Ar]\, 4s^2 3d^5$	**1 point**
(ii)	For the correct answer, consistent with part (a)(i): $4s$	**1 point**
	Total for part (a)	**2 points**
(b)	For the correct calculated value: $62.673\text{ g} - 61.262\text{ g} = 1.411\text{ g Cl}$	**1 point**
(c)	For the correct calculated value, consistent with part (b): $1.411\text{ g Cl} \times \frac{1\text{ mol Cl}}{35.45\text{ g Cl}} = 0.03980\text{ mol Cl}$	**1 point**
(d)	For the correct answer, consistent with part (c): $\frac{0.03980\text{ mol Cl}}{0.0199\text{ mol Mn}} = \frac{2\text{ mol Cl}}{1\text{ mol Mn}} \Rightarrow \text{MnCl}_2$	**1 point**
(e)	For the correct answer and a valid justification: *Less than. If some of the mass of aqueous Mn_xCl_y is lost due to splattering, the final mass of the dry beaker and Mn_xCl_y will be decreased, which will decrease the calculated mass and number of moles of chlorine in the dry solid.*	**1 point**

(f) (i)	For the correct balanced equation: $$\begin{array}{r} 2\ MnO_2(s) + H_2O(l) + 2\ e^- \rightarrow Mn_2O_3(s) + 2\ OH^-(aq) \\ Zn(s) + 2\ OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2\ e^- \\ \hline 2\ MnO_2(s) + Zn(s) \rightarrow Mn_2O_3(s) + ZnO(s) \end{array}$$	**1 point**
(ii)	For the correct calculated value, consistent with part (f)(i): $E^\circ_{cell} = 0.15\text{ V} - (-1.28\text{ V}) = 1.43\text{ V}$	**1 point**
(iii)	For the correct calculated value, consistent with part (f)(ii): $\Delta G^\circ = -nFE^\circ = -\frac{2\text{ mol } e^-}{1\text{ mol}_{rxn}} \times \frac{96{,}485\text{ C}}{1\text{ mol } e^-} \times \frac{1.43\text{ J}}{1\text{ C}} \times \frac{1\text{ kJ}}{1000\text{ J}} = -276\text{ kJ/mol}_{rxn}$	**1 point**
(iv)	For the correct answer and a valid justification: Accept one of the following: • *Disagree. The battery is enclosed, so no change in the total mass will occur.* • *Disagree. All reactants and products are in the solid phase, so the mass of the sealed battery will remain the same (no gases enter or exit the battery).*	**1 point**
	Total for part (f)	**4 points**
	Total for question 1	**10 points**