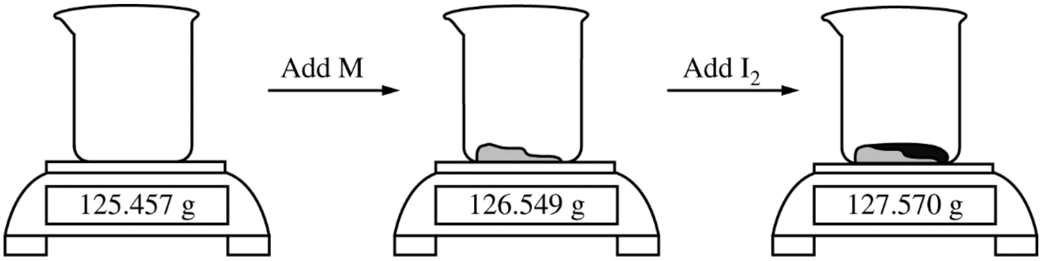
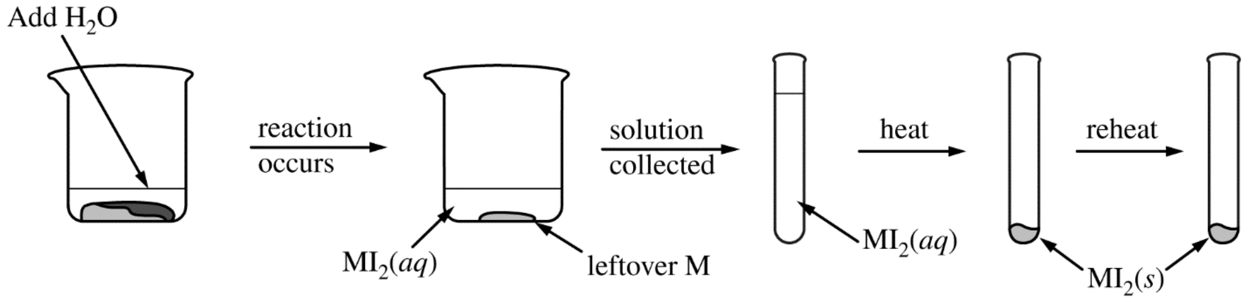
Question 3

$$M + I_2 \rightarrow MI_2$$

To determine the molar mass of an unknown metal, M, a student reacts iodine with an excess of the metal to form the water-soluble compound MI_2, as represented by the equation above. The reaction proceeds until all of the I_2 is consumed. The $MI_2(aq)$ solution is quantitatively collected and heated to remove the water, and the product is dried and weighed to constant mass. The experimental steps are represented below, followed by a data table.





Data for Unknown Metal Lab	
Mass of beaker	125.457 g
Mass of beaker + metal M	126.549 g
Mass of beaker + metal M + I_2	127.570 g
Mass of MI_2, first weighing	1.284 g
Mass of MI_2, second weighing	1.284 g

Question 3 (continued)

(a) Given that the metal M is in excess, calculate the number of moles of I_2 that reacted.

$127.570 - 126.549 = 1.021\text{ g } I_2$ $1.021\text{ g } I_2 \times \frac{1\text{ mol } I_2}{253.80\text{ g } I_2} = 0.004023\text{ mol } I_2$	1 point is earned for the number of moles.

(b) Calculate the molar mass of the unknown metal M.

Number of moles of I_2 = number of moles of M $1.284\text{ g } MI_2 - 1.021\text{ g } I_2 = 0.263\text{ g M}$ Molar mass of M $= \frac{0.263\text{ g M}}{0.004023\text{ mol M}} = 65.4$ g/mol	1 point is earned for the number of grams of M. 1 point is earned for the molar mass.

The student hypothesizes that the compound formed in the synthesis reaction is ionic.

(c) Propose an experimental test the student could perform that could be used to support the hypothesis. Explain how the results of the test would support the hypothesis if the substance was ionic.

The student could dissolve the compound in water or melt the compound and see if the solution/melt conducts electricity. If the solution/melt conducts electricity, mobile ions capable of carrying charge must be present, thus the compound is likely to be ionic. OR The student could heat the compound until it melts or boils. If the melting/boiling point is very high, then the compound is likely to be ionic.	1 point is earned for an appropriate test. 1 point is earned for explaining how the results would support the hypothesis.

The student hypothesizes that Br_2 will react with metal M more vigorously than I_2 did because Br_2 is a liquid at room temperature.

Question 3 (continued)

(d) Explain why I_2 is a solid at room temperature whereas Br_2 is a liquid. Your explanation should clearly reference the types and relative strengths of the intermolecular forces present in each substance.

Both Br_2 and I_2 molecules are nonpolar molecules, therefore the only possible intermolecular forces are London dispersion forces. The London dispersion forces are stronger in I_2 because it is larger in size with more electrons and/or a more polarizable electron cloud. The stronger London dispersion forces in I_2 result in a higher melting point,which makes I_2 a solid at room temperature.	1 point is earned for identifying the forces in each substance as London dispersion forces. 1 point is earned for explaining why the forces are stronger in I_2 than in Br_2.

While cleaning up after the experiment, the student wishes to dispose of the unused solid I_2 in a responsible manner. The student decides to convert the solid I_2 to $I^-(aq)$ anion. The student has access to three solutions, $H_2O_2(aq)$, $Na_2S_2O_3(aq)$, and $Na_2S_4O_6(aq)$, and the standard reduction table shown below.

Half-reaction	$E°$ (V)
$S_4O_6^{2-}(aq) + 2\,e^- \rightarrow 2\,S_2O_3^{2-}(aq)$	0.08
$I_2(s) + 2\,e^- \rightarrow 2\,I^-(aq)$	0.54
$O_2(g) + 2\,H^+(aq) + 2\,e^- \rightarrow H_2O_2(aq)$	0.68

(e) Which solution should the student add to $I_2(s)$ to reduce it to $I^-(aq)$? Circle your answer below. Justify your answer and include a calculation of $E°$ for the overall reaction.

$H_2O_2(aq)$ $\qquad$ $Na_2S_2O_3(aq)$ $\qquad$ $Na_2S_4O_6(aq)$

[$Na_2S_2O_3(aq)$ should be circled.] The reaction between $S_2O_3^{2-}(aq)$ and $I_2(s)$ will be thermodynamically favorable because $E°$ for the reaction is positive ($E° = 0.54 - 0.08 = +0.46$ V), from which it follows that $\Delta G°$ is negative because $\Delta G° = -nFE°$.	1 point is earned for the correct choice. 1 point is earned for a correct justification.

(f) Write the balanced net-ionic equation for the reaction between I_2 and the solution you selected in part (e).

$I_2 + 2\,S_2O_3^{2-} \rightarrow 2\,I^- + S_4O_6^{2-}$	1 point is earned for the correct equation.

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The student hypothesizes that Br_2 will react with metal M more vigorously than I_2 did because Br_2 is a liquid at room temperature.

(d) Explain why I_2 is a solid at room temperature whereas Br_2 is a liquid. Your explanation should clearly reference the types and relative strengths of the intermolecular forces present in each substance.

While cleaning up after the experiment, the student wishes to dispose of the unused solid I_2 in a responsible manner. The student decides to convert the solid I_2 to $I^-(aq)$ anion. The student has access to three solutions, $H_2O_2(aq)$, $Na_2S_2O_3(aq)$, and $Na_2S_4O_6(aq)$, and the standard reduction table shown below.

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$O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O_2(aq)$	0.68

(e) Which solution should the student add to $I_2(s)$ to reduce it to $I^-(aq)$? Circle your answer below. Justify your answer, including a calculation of $E°$ for the overall reaction.

$H_2O_2(aq)$ [✓ $Na_2S_2O_3(aq)$] $Na_2S_4O_6(aq)$

(f) Write the balanced net-ionic equation for the reaction between I_2 and the solution you selected in part (e).

a.) ~~1.284g MI₂~~ 127.570g beaker + M+I₂ − 126.549g beaker + M = 1.021g I₂

1.021g I₂ · $\frac{1 \text{mol } I_2}{253.8g}$ = ~~4.023 mol I₂~~ $\boxed{4.023 \times 10^{-3} \text{ mol } I_2}$ assuming all I₂ reacted

b.) 1.284g MI₂ − 1.021g I₂ = .263 g M

4.023×10^{-3} mol I₂ · $\frac{1 \text{mol } M}{1 \text{mol } I_2}$ = 4.023×10^{-3} mol M

$\frac{.263 g M}{4.023 \times 10^{-3} \text{ mol } M}$ = $\boxed{65.4 \text{ g/mol}}$

c.) The student could redissolve the compound in water then test to see if it conducted electricity (set up a circuit connected to a lightbulb so that current will pass through the solution). If it is ionic the solution will conduct electricity (the lightbulb will light up when current is passed through the solution).

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d.) Since Br_2 and I_2 are both symmetrical and are 2 ~~of~~ of the same atoms, they aren't polar. The only IMFs that can exist for either are London dispersion forces, which are caused when the e^- instantaneously shift to one side of the molecule to create an instantaneous dipole. Since I_2 is larger, it ~~can~~ has more e^- so its ~~can create~~ dispersion forces are stronger than Br_2 (greater magnitude of charge difference btwn poles of molecule). I_2 would ~~be a~~ have a higher melting point b/c it would take more energy to break its dispersion forces than ~~Br_2's~~ those of Br_2

E°

e.) cathode rxn (reduction) : $I_2 + 2e^- \rightarrow 2I^-$ $+.54$ V

anode rxn (oxidation) : $2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2e^-$ $-.08$ V

$.54V - .08V = \boxed{.46V}$

you must have an oxidation reaction and

E°_{cell} must be positive for the rxn to be spontaneous so the E° of the anode (where oxidation occurs) must be $< .54$ since you want I_2 to be reduced. ~~$Na_2S_2O_3$ would~~ Therefore the student would need to use $Na_2S_2O_3$.

f.) $I_2(s) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$

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The student hypothesizes that Br_2 will react with metal M more vigorously than I_2 did because Br_2 is a liquid at room temperature.

(d) Explain why I_2 is a solid at room temperature whereas Br_2 is a liquid. Your explanation should clearly reference the types and relative strengths of the intermolecular forces present in each substance.

While cleaning up after the experiment, the student wishes to dispose of the unused solid I_2 in a responsible manner. The student decides to convert the solid I_2 to $I^-(aq)$ anion. The student has access to three solutions, $H_2O_2(aq)$, $Na_2S_2O_3(aq)$, and $Na_2S_4O_6(aq)$, and the standard reduction table shown below.

Half reaction	$E°$ (V)
$S_4O_6^{2-}(aq) + 2\,e^- \rightarrow 2\,S_2O_3^{2-}(aq)$	0.08
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$O_2(g) + 2\,H^+(aq) + 2\,e^- \rightarrow H_2O_2(aq)$	0.68

$I_2 + 2e^-$
↓
reduction

~~oxidizing~~

→ red

oxid

~~oxidizi~~

(e) Which solution should the student add to $I_2(s)$ to reduce it to $I^-(aq)$? Circle your answer below. Justify your answer, including a calculation of $E°$ for the overall reaction.

$H_2O_2(aq)$ [✓ $Na_2S_2O_3(aq)$] ~~$Na_2S_4O_6(aq)$~~

(f) Write the balanced net-ionic equation for the reaction between I_2 and the solution you selected in part (e).

(a) ~~$MI_2 = 1.284g$~~

$127.570g - 126.549g = 1.021g\ I_2$

$1.021g\ I_2 \times \frac{1\ mol}{253.8g\ I_2} = 4.023 \times 10^{-3}\ mol$

(b) $4.023 \times 10^{-3}\ mol\ I_2 \times \frac{1\ mol\ MI_2}{1\ mol\ I_2} = 4.023 \times 10^{-3}\ mol\ MI_2$

$\frac{1.284g}{4.023 \times 10^{-3}\ mol} = 319.2g/mol$

$I_2 = 253.8g/mol \quad M = 319.2g/mol - 253.8g/mol = 65.4g/mol$

Zn

(c) Dissolve the MI_2 into the water.
Send a current through the solution and check if it conducts electricity.
Make sure you check if the solid form conducts

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electricity. If it doesn't conduct electricity in solid form and does in an aqueous form, it is an ionic compound.

(d) Br – Br MP s → l **MP↓**

$:\ddot{\underset{\cdot\cdot}{I}}-\ddot{\underset{\cdot\cdot}{I}}:$ BP l → g weaker

Both I_2 and Br_2 contain non polar covalent bond. I_2 has bigger electron cloud than Br_2, making it more polarizable. More polarizable means stronger IMF, so its melting point is also higher than Br_2. Therefore, I_2 is a solid ~~at~~ room temperature while Br_2 is a liquid.

(e) I_2 becomes I^- through reduction process. Good reducing agent is the one that oxidized easily. From the chart, we know that $Na_2S_2O_3$ oxidizes easily due to small E° value.

(f) ~~I_2 + $Na_2S_4O_6$~~

$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^-$

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The student hypothesizes that Br_2 will react with metal M more vigorously than I_2 did because Br_2 is a liquid at room temperature.

(d) Explain why I_2 is a solid at room temperature whereas Br_2 is a liquid. Your explanation should clearly reference the types and relative strengths of the intermolecular forces present in each substance.

While cleaning up after the experiment, the student wishes to dispose of the unused solid I_2 in a responsible manner. The student decides to convert the solid I_2 to $I^-(aq)$ anion. The student has access to three solutions, $H_2O_2(aq)$, $Na_2S_2O_3(aq)$, and $Na_2S_4O_6(aq)$, and the standard reduction table shown below.

Half reaction	$E°$ (V)
$\overset{+}{S}_4O_6^{2-}(aq) + 2e^- \rightarrow 2\,\overset{+2}{S}_2O_3^{2-}(aq)$	0.08
$I_2(s) + 2e^- \rightarrow 2\,I^-(aq)$	0.54
$\overset{0}{O}_2(g) + 2\,H^+(aq) + 2e^- \rightarrow \overset{+1}{H}_2\overset{-1}{O}_2(aq)$	0.68

(e) Which solution should the student add to $I_2(s)$ to reduce it to $I^-(aq)$? Circle your answer below. Justify your answer, including a calculation of $E°$ for the overall reaction.

[✓ $H_2O_2(aq)$] $Na_2S_2O_3(aq)$ $Na_2S_4O_6(aq)$

(f) Write the balanced net-ionic equation for the reaction between I_2 and the solution you selected in part (e).

a) 127.570g − 126.549g = 1.021g I_2 | $\frac{1n}{253.8g\,I_2}$ = .004023 n I_2

b) 126.549g − 125.457g = 1.092g | $\frac{1n}{1.284g}$ = .85 n M

c) We could test the boiling point of the compound. Ionic compounds generally have high boiling points, so we could see if the compound had a high BP.

d) I_2 has stronger intermolecular forces. Since they both have dispersion forces, I_2 is stronger b/c it has more electrons.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

e) to reduce I_2 to I, we need E° cell to be (-)

f) $H_2O_2 \rightarrow O_2 + 2H^+ + \cancel{2e^-}$

$\cancel{2e^-} + I_2 \rightarrow 2I^-$

$$H_2O_2(aq) + I_2(s) \rightarrow O_{2(g)} + 2H^+_{(aq)} + 2I^-(aq)$$

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Question 3

Overview

Question 3 evaluated students' ability to analyze data from a common laboratory experiment. Students were given pictures of the experimental steps to synthesize and collect the ionic solid, MI_2. In part (a) students calculated the moles of I_2 that reacted with an excess of metal M. In part (b) the value from part (a) was used to calculate the molar mass of the metal M. In part (c) students proposed an experimental test that could be used to determine if MI_2 is an ionic solid, and then explained how the results of the test supported this claim. Students explained why I_2 is solid at room temperature, but Br_2 is a liquid in part (d). In part (e) students utilized a standard reduction potential chart to choose which species, H_2O_2, $Na_2S_2O_3$ or $Na_2S_4O_6$ could reduce the leftover I_2, and then to justify their claim. Students wrote the net-ionic equation for the reaction between I_2 and the solution they chose in part (e).

Sample: 3A
Score: 10

The point was earned in part (a) for correctly calculating the number of moles of I_2 that reacted with metal M. Both points were earned in part (b) for determining the mass and molar mass of metal M. Both points were earned in part (c): the student proposes to test the conductivity of an aqueous MI_2 solution and states that if the solution conducts electricity this confirms that MI_2 is ionic. In part (d) the first point was earned for indicating that London dispersion forces are present in both I_2 and Br_2. The second point in part (d) was earned for explaining that I_2 is a larger molecule with more electrons and, therefore, stronger dispersion forces. In part (e) 2 points were earned for correctly choosing $Na_2S_2O_3$ solution to reduce I_2 to I^-. The student justifies the choice with the reaction cell voltage and by stating that a positive $E°$ indicates a spontaneous reaction. In part (f) 1 point was earned for the balanced net-ionic equation between I_2 and $Na_2S_2O_3$.

Sample: 3B
Score: 8

The student earned 1 point in part (a) for the correct number of moles of I_2. In part (b) 2 points were earned for the correct molar mass of the metal M. In part (c) the student earned both points for the proposal to test the conductivity of an aqueous solution of MI_2 and the explanation of how the test supports the hypothesis. In part (d) only 1 of the points was earned. The student does not indicate what type of intermolecular forces are present in I_2 and Br_2; however, the student explains that the forces in I_2 are stronger because I_2 has a bigger electron cloud that is more polarizable. Only 1 point was earned in part (e). The student selects $Na_2S_2O_3$ to reduce I_2 to I^-; however, the second point was not earned because there is no calculation with the justification. In part (f) 1 point was earned for the correct net-ionic equation.

Question 3 (continued)

Sample: 3C
Score: 6

In part (a) 1 point was earned because the student calculates the number of moles of I_2 correctly. Part (b) earned 0 points; the mass of the metal, M, is incorrect and the student does not use the correct number of moles of M to determine the molar mass. Both points were earned in part (c): 1 point was earned for suggesting that the boiling point of the MI_2 could be used to determine if MI_2 is ionic and another point was earned for stating that ionic compounds have high boiling points. Both points were earned in part (d) for the identification of the correct intermolecular forces in I_2 and Br_2 and for explaining why the forces are stronger in I_2. In part (e) the student choses the incorrect solution to reduce I_2 and earned 0 points. In part (f) 1 point was earned for a correct net-ionic equation that is consistent with the student's choice in part (e).