Write This, Not That!

on the AP Chemistry Exam

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Sources:
- Released Free-Response Questions with Samples and Commentary/Chief Reader Reports
- AACT Webinars: Lessons Learned from AP Chemistry Exam

All practice problems are taken from previous AP Chemistry Exams and are property of the College Board.

*IPE stands for International Practice Exam.

*FRQ stands for free response question and are the questions publicly released from the exam.

Updated April 15th, 2024

My biggest pieces of advice to get all your points!

- **Show all work!**
    - If you don’t show work, you don’t earn credit
    - Label units and plug in actual values for variables – it helps readers see your process
- **Read the question and answer THAT question**
    - If it says “using the data above”, you must reference the actual data in your answer
    - If it says “include units”, you must include units
- **Justify your answers using chemical principles!**
    - Don’t use definitions, they won’t help
    - Don’t restate the prompt as your reason
    - If it says “justify” and you do not, you’ll probably earn no points
- **Make it to the end!**
    - Jump around in the exam – do the questions you feel best about first
    - Don’t give up on a whole FRQ if the early parts are hard for you – the questions often change topic in the middle

Table of Contents

For All Questions

Write This…	…Not That!	Rationale
Handwriting that is clear, legible, dark enough and large enough to be scanned and read by someone who doesn't know you	Messy, illegible, light, tiny writing that cannot be read	Answers deemed illegible by a reader and the table leader will earn no points on corresponding parts/questions – remember all papers are SCANNED
Variables that are clearly denoted and appropriately used	Variables that are incorrectly represented	Variables have specific meaning and must be correctly denoted/abbreviated; case matters for many variables: • M (not m) for molarity, • K (equilibrium constant) vs k (rate constant) • m is meters, not minutes, moles or molarity, etc.
Numerical answers that are supported by work	Numerical answers on their own	Work is required to be shown in order for points to be earned
Abbreviations that are generally accepted (M, min, s, IMF, LDF, etc.)	Abbreviations that are not generally accepted/ are incorrect/ change the meaning (ex: mol for molecule, CL instead of Coulomb's Law, etc)	Abbreviations still must convey the correct information; if in doubt, define or avoid them – don't create ambiguity in an answer by using an abbreviation
Answer the specific question first, then "justify", "explain" etc.	Burying the answer in the text of the response	Make it easy to follow your answer and give you points
Answers that are concise and direct	Burying the answer in a long response	Make it easy to follow your answer and give you points
Names of specific elements and compounds, "reactants", "products", etc.	"it"	Ambiguous

For All Questions (cont.)

Write This…	…Not That!	Rationale
Symbols that match that in a provided key for a diagram	Making up symbols for a diagram	Use the provided key to ensure that you are clear in your answer (ref 2023 #5b)
A justification or explanation when it is requested as part of the question	Only the answer without supporting it	Justification/explanation required to earn point
“mass”, “volume”, etc.	“size”	Be specific to indicate understanding
References to specific data or graphs when prompted to “explain how the data…”, “using the table below…” or something similar	Generalizations about the data without specifically citing provided data or trials	Required to earn point (ref. 2023 #3b)
Elements that match the symbol given in the prompt	Elements that are do not match the symbol in the prompt	Be careful – some elements have similar symbols! (Ex: Cl and C) (ref. 2023 #1)
An answer with units if “include units” is stated in the problem	An answer without units	If “include units” is written in the prompt, correct unit is required to earn full points
Complete dimensional analysis/work with units	Incomplete dimensional analysis without units	Including units clearly shows intended work, and allows points for “implied” calculations to be earned
Values with units that match constants and that are the same throughout the equation	Values with units that do not match other values/constants	Values must be the same unit through an equation, for both constants and variables

For All Questions (cont.)

Write This…	…Not That!	Rationale
Answers expressed to the correct number of significant figures, based on data given in the problem	Answers with an incorrect number of significant figures or significant figures limited by molar mass, constants, etc.	1 pt traditionally is assessed somewhere in the FR for significant figures (typically found in a laboratory data question)
Answers that only refer to substances/data included in the prompt	Answers with justifications based on situations or data that are not indicated in the prompt	Do not claim something happened that was not present in prompt– any valid assumptions would be stated
Analysis of given data in a thoughtful way that is based on chemical principles	Saying that data is wrong, that the data is impossible, calling the test writers liars, etc.	The AP Exam is never going to try to trick you- it will not give false or impossible data
Answers that refer to specific and correct glassware, used correctly (ex: buret rinsed then filled), and values read correctly from figures	Answers that use incorrect glassware for the task, particularly with regard to precision and/or misread figures of glassware	Glassware has different specialized uses, and should be appropriately referenced/used/read based on the task (ex. 2023 #4b)
Explanation of an application of usage of a term	Definition of a term	A definition is not required on the exam – an explanation of how this term applies is needed
An explanation of the reason behind an observation of phenomena.	Stating a law/rule or observation without explaining the chemical principles or phenomena behind the law/rule/trend.	Simply stating the end result without discussing the reason for that result does not fully answer the question. Evidence and reasoning must both be included. (ex. 2019 #4, 2023 #7c)
Using deductive reasoning to make conclusions or approximate values when the terms “estimate” or “justify” are in the prompt	Using long, time-intensive math reasoning when “calculate” is not indicated in the prompt	While correct calculations will earn credit, the loss in this type of answer is the amount of time spent on the calculations when an assessment without lengthy calculations can be done instead (ex: 2018 #2e-f, 2019 #3g)

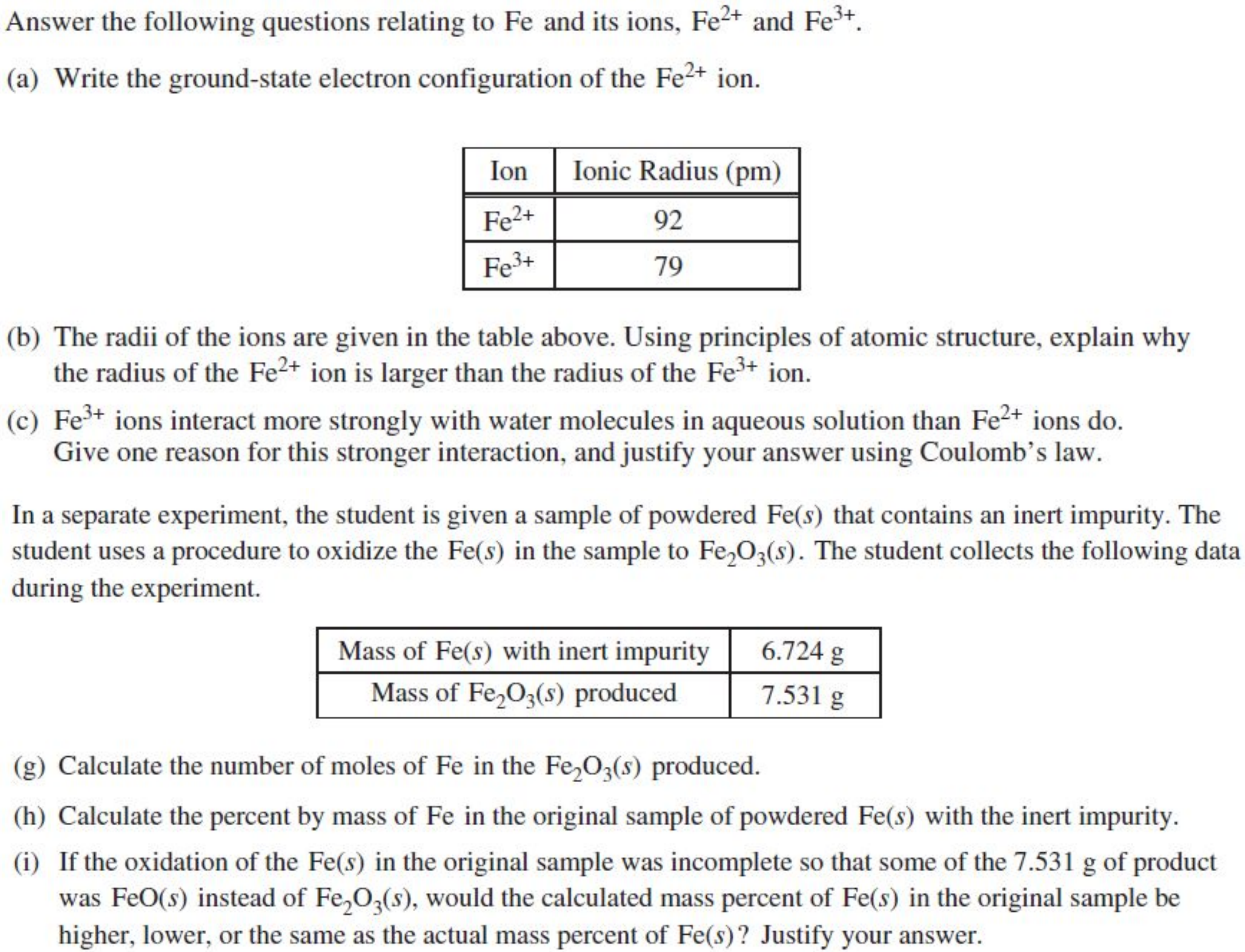
For All Questions (cont.)

Write This…	…Not That!	Rationale
Answers that pay attention to the relative scale on graphs	Answers that make assumptions on the scale without examining data	Don’t assume that marked lines automatically are increments of 1, 10, etc. – use the data to determine the scale (ex. 2019 #5a)
Answers that make absolute comparisons (greater than 1, less than 1)	Answers that make vague comparisons (more, less)	If it is possible to justify an answer with values, do that to demonstrate that you understand the underlying principle (C.R. 2023)
Write out the value of R (and all constants) in your work	Showing the variable instead of the value of the constant	The correct symbol used correctly will earn full points, HOWEVER – students that write out the value are more likely to use the correct value in their calculation (C.R.R. 2023)
Correct symbols or terms	Incorrect symbols	Be sure to use the correct < or >, if in doubt, use words instead (C.R.R. 2023)
Algebraic rearrangements that correctly follow order of operations and isolate the desired term	Incorrect algebra	Be careful to rearrange equations correctly – watch when to multiple/divide, and what is in numerator or denominator (ex. 2021 #3d, 2023 #5b, 2023 #7bii)
Answers that pay attention to the relative scale on graphs	Answers that make assumptions on the scale without examining data	Don’t assume that marked lines automatically are increments of 1, 10, etc. – use the data to determine the scale (ex. 2019 #5a)
Answers that make absolute comparisons (greater than 1, less than 1)	Answers that make vague comparisons (more, less)	If it is possible to justify an answer with values, do that to demonstrate that you understand the underlying principle (C.R. 2023)

Unit 1: Atomic Structure and Properties

Write This…	…Not That!	Rationale
"period"	"shell" when referring to elements and their location on the Periodic Table	Elements are in a period, electrons are in a shell
Ion electron configurations that show electrons were removed from valence shell orbitals	Ion electron configurations that show electrons were removed from inner orbitals	Ions form by electrons being lost from the outermost shell; this may or may not be the electrons that were filled last in the electron configuration (ref. 2018 #3a)
Reference reasons for periodic trends (i.e. effective nuclear charge, Coulomb's law, polarizability, etc.)	Stating the trend as the reason ("because it is to the left", "because it is further down the periodic table", etc.)	State the actual reason not the memory aid (Ref. 2021 #2h, 2022 #3b)
"Effective nuclear charge increases"	"It wants to have a full octet"; "it's close to having a full octet"	State the actual reason not the memory aid
"It has a more polarizable cloud of electrons"	"It has more electrons", "it has more mass", "it has more surface area", "it is bigger", "it has more protons"	State the actual reason not the memory aid
"Electrons in higher energy levels are farther from the nucleus, resulting in a larger atom/ion."	"More electrons/more energy levels makes the atom/ion bigger."	Explanation of reason, not just statement of fact, required for point (Ref 2016 #1)
Using the difference in mass from given lab data to determine the mass of a desired product	Using lab data without removing the mass of species not in the desired product	Difference in mass is used to account for mass of filter paper, drying agent, unreacted starting material, etc. (Ref. 2021 #3b)

Unit 1 Practice Problem – 2018 FRQ #3



Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(a) Write the ground-state electron configuration of the Fe^{2+} ion.

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

(b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

(c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

In a separate experiment, the student is given a sample of powdered Fe(*s*) that contains an inert impurity. The student uses a procedure to oxidize the Fe(*s*) in the sample to $Fe_2O_3(s)$. The student collects the following data during the experiment.

Mass of Fe(*s*) with inert impurity	6.724 g
Mass of $Fe_2O_3(s)$ produced	7.531 g

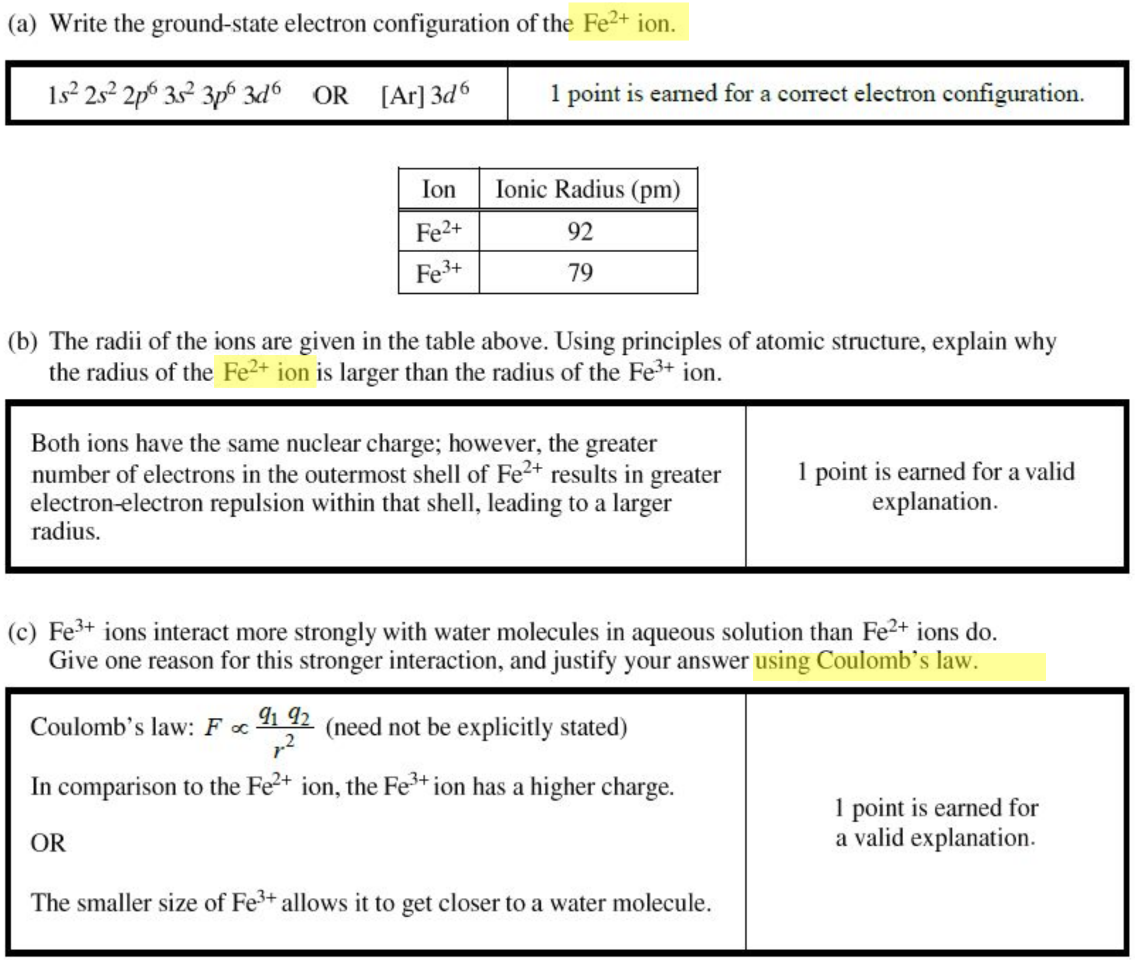
(g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

(h) Calculate the percent by mass of Fe in the original sample of powdered Fe(*s*) with the inert impurity.

(i) If the oxidation of the Fe(*s*) in the original sample was incomplete so that some of the 7.531 g of product was FeO(*s*) instead of $Fe_2O_3(s)$, would the calculated mass percent of Fe(*s*) in the original sample be higher, lower, or the same as the actual mass percent of Fe(*s*)? Justify your answer.

Parts d-f pertain to different units and were removed for this example

2018 FRQ #3 Scoring Guidelines and Things to Notice



(a) Write the ground-state electron configuration of the Fe^{2+} ion.

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$ OR $[Ar]\ 3d^6$	1 point is earned for a correct electron configuration.

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

(b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

Both ions have the same nuclear charge; however, the greater number of electrons in the outermost shell of Fe^{2+} results in greater electron-electron repulsion within that shell, leading to a larger radius.	1 point is earned for a valid explanation.

(c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

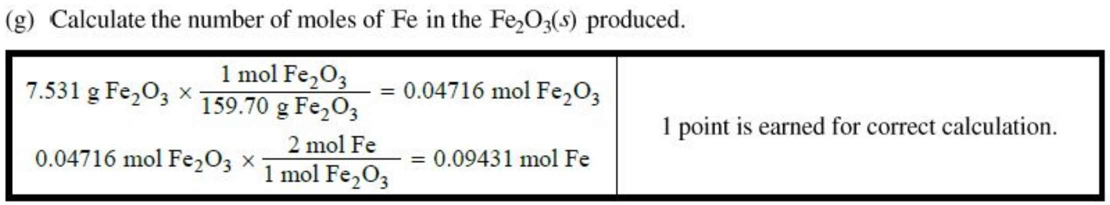
Coulomb's law: $F \propto \frac{q_1 q_2}{r^2}$ (need not be explicitly stated) In comparison to the Fe^{2+} ion, the Fe^{3+} ion has a higher charge. OR The smaller size of Fe^{3+} allows it to get closer to a water molecule.	1 point is earned for a valid explanation.

- Notice that this electron configuration is for an ion, and that the two electrons were lost from the valence shell (not the last filled shell)

- Notice that the response references both ions but then the justification is in terms of the Fe^{2+} (because the prompt asks why the Fe^{2+} is larger)

- Because you are told to justify using Coulomb's law, the explanation will not be correct without referencing features of the law at play

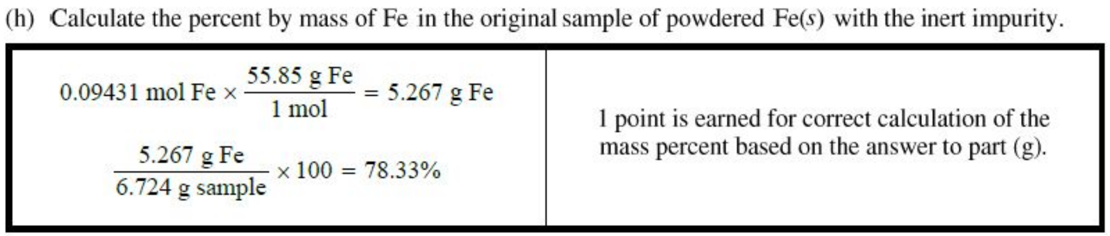
2018 FRQ #3 Scoring Guidelines and Things to Notice (cont).



(g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

$7.531\text{ g }Fe_2O_3 \times \frac{1\text{ mol }Fe_2O_3}{159.70\text{ g }Fe_2O_3} = 0.04716\text{ mol }Fe_2O_3$ $0.04716\text{ mol }Fe_2O_3 \times \frac{2\text{ mol Fe}}{1\text{ mol }Fe_2O_3} = 0.09431\text{ mol Fe}$	1 point is earned for correct calculation.

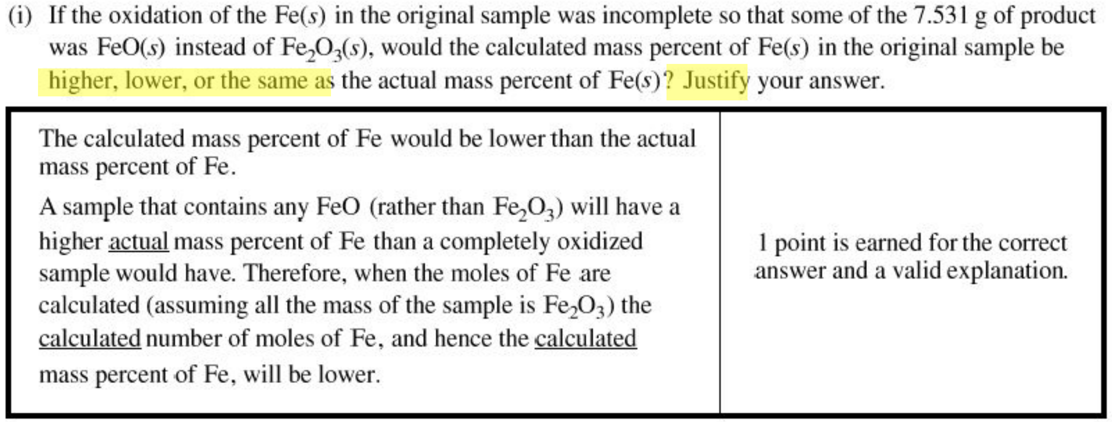
- Show all work and make it easy to follow by using units and math that has a logical progression on the page



(h) Calculate the percent by mass of Fe in the original sample of powdered Fe(*s*) with the inert impurity.

$0.09431\text{ mol Fe} \times \frac{55.85\text{ g Fe}}{1\text{ mol}} = 5.267\text{ g Fe}$ $\frac{5.267\text{ g Fe}}{6.724\text{ g sample}} \times 100 = 78.33\%$	1 point is earned for correct calculation of the mass percent based on the answer to part (g).

- Remember: no double jeopardy; using an incorrect answer from part g will still give the point here if this part is done correctly



(i) If the oxidation of the Fe(*s*) in the original sample was incomplete so that some of the 7.531 g of product was FeO(*s*) instead of $Fe_2O_3(s)$, would the calculated mass percent of Fe(*s*) in the original sample be higher, lower, or the same as the actual mass percent of Fe(*s*)? Justify your answer.

The calculated mass percent of Fe would be lower than the actual mass percent of Fe. A sample that contains any FeO (rather than Fe_2O_3) will have a higher actual mass percent of Fe than a completely oxidized sample would have. Therefore, when the moles of Fe are calculated (assuming all the mass of the sample is Fe_2O_3) the calculated number of moles of Fe, and hence the calculated mass percent of Fe, will be lower.	1 point is earned for the correct answer and a valid explanation.

- Answer the question first: “lower”
- Justify second. Notice that the point is not earned without the justification – it must be included.
- Don’t let wording through you off – you don’t need to do anything with oxidation here, it’s all thinking about the impact of an leftover reactant on calculations in an experiment

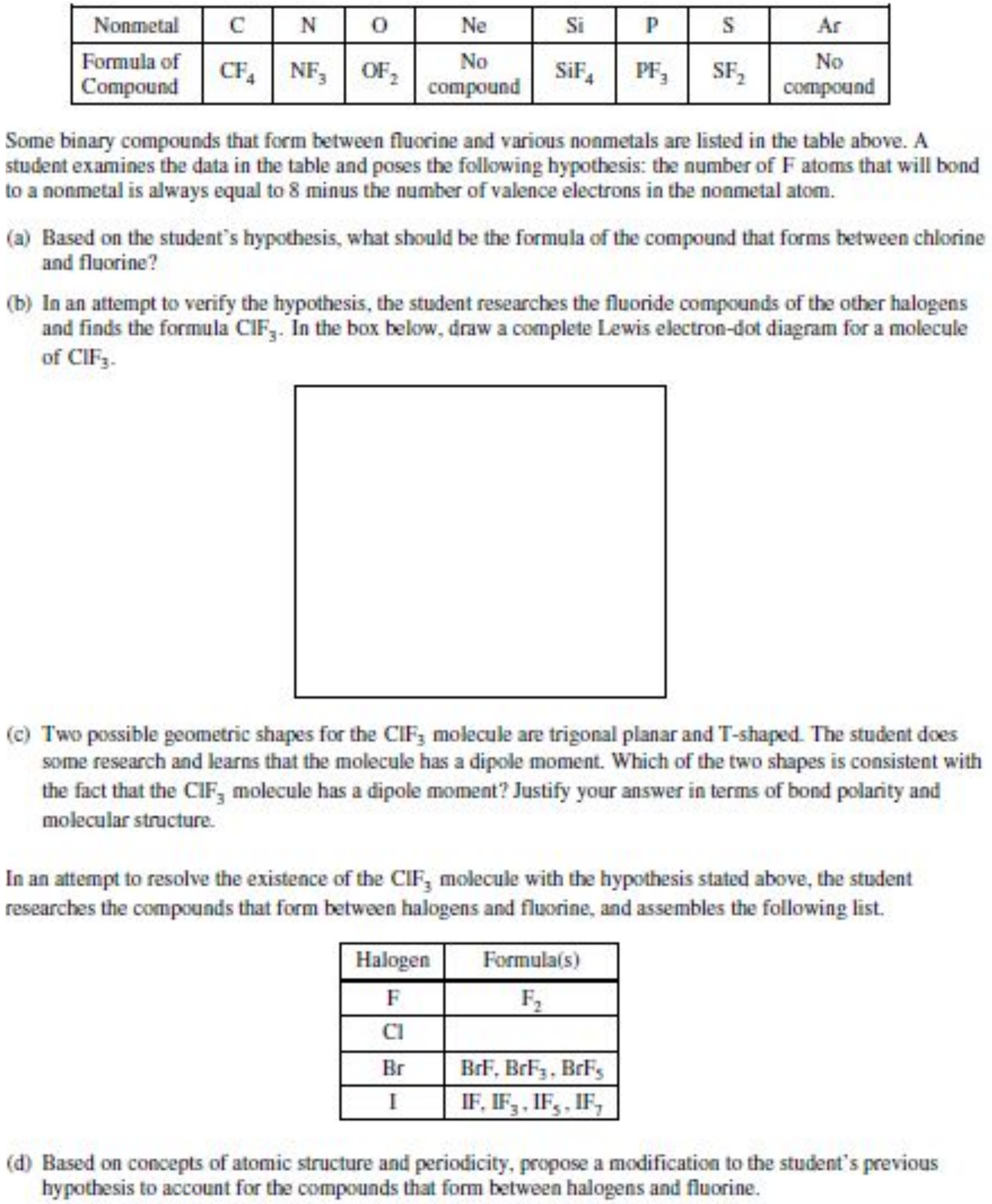
Unit 2: Molecular and Ionic Compound Structure and Properties

Write This…	…Not That!	Rationale
Explaining properties of a solid/substance by discussing the components and bonds within	Attributing properties of a solid/substance to its type without explaining the structural reason	Structural features are required to justify properties of a substance (i.e. types of bonds, mobile charges, etc) (Ref. 2021 #6a)
"ionic compound"	"molecule" when discussing an ionic compound	A molecule is a covalent compound
"ions"	"atoms" when discussing ionic compounds	Ionic compounds contain ions – this shows the understanding that it is the charges that form the bond
"atoms"	"ions" when discussing covalent compounds	Covalent compounds do not contain ions
"Coulombic attraction"	"Opposites attract"	State the actual reason not the memory aid
Lewis structures that obey the octet rule	Lewis structures that violate the octet rule	Lewis structures must obey the octet rule, except in the case of expanded octets (Ref 2021 #1c)
Lewis structures that are complete with necessary lone pairs and/or resonance	Lewis structures that are missing lone pairs and/or resonance (if needed for correct structures)	Lewis structures are incorrect without necessary lone pairs/resonance
Multiple bonds when there are not enough valence electrons to satisfy the octet rule	Multiple bonds when the octet rule for the structure would have been satisfied without them	Multiple bonds are only needed when there are not enough valence electrons to satisfy the octet rule

Unit 2: Molecular and Ionic Compound Structure and Properties (cont.)

Write This…	…Not That!	Rationale
VSEPR geometry/hybridization that considers the 3D arrangement of atoms in a molecule	VSEPR geometry/hybridization that considers a molecule based on its 2D representation	VSEPR/hybridization are used to describe the 3D arrangement of atoms in a molecule; failing to recognize the difference between the way a Lewis structure is drawn and the way the actual molecule is arranged may lead to an incorrect analysis of structure (ref. 2018 #2d)
Molecular geometries that consider the impact of lone pairs on the overall geometry (i.e. molecular geometries)	Molecular geometries that treat lone pairs and bonding pairs the same (i.e. electron group geometries)	The molecular and electron group geometries are identical only if all electron groups are bonding (ref. 2023 #2di)

Unit 2 Practice Problem - 2014 IPE #5



Nonmetal	C	N	O	Ne	Si	P	S	Ar
Formula of Compound	CF_4	NF_3	OF_2	No compound	SiF_4	PF_3	SF_2	No compound

Some binary compounds that form between fluorine and various nonmetals are listed in the table above. A student examines the data in the table and poses the following hypothesis: the number of F atoms that will bond to a nonmetal is always equal to 8 minus the number of valence electrons in the nonmetal atom.

(a) Based on the student's hypothesis, what should be the formula of the compound that forms between chlorine and fluorine?

(b) In an attempt to verify the hypothesis, the student researches the fluoride compounds of the other halogens and finds the formula ClF_3. In the box below, draw a complete Lewis electron-dot diagram for a molecule of ClF_3.

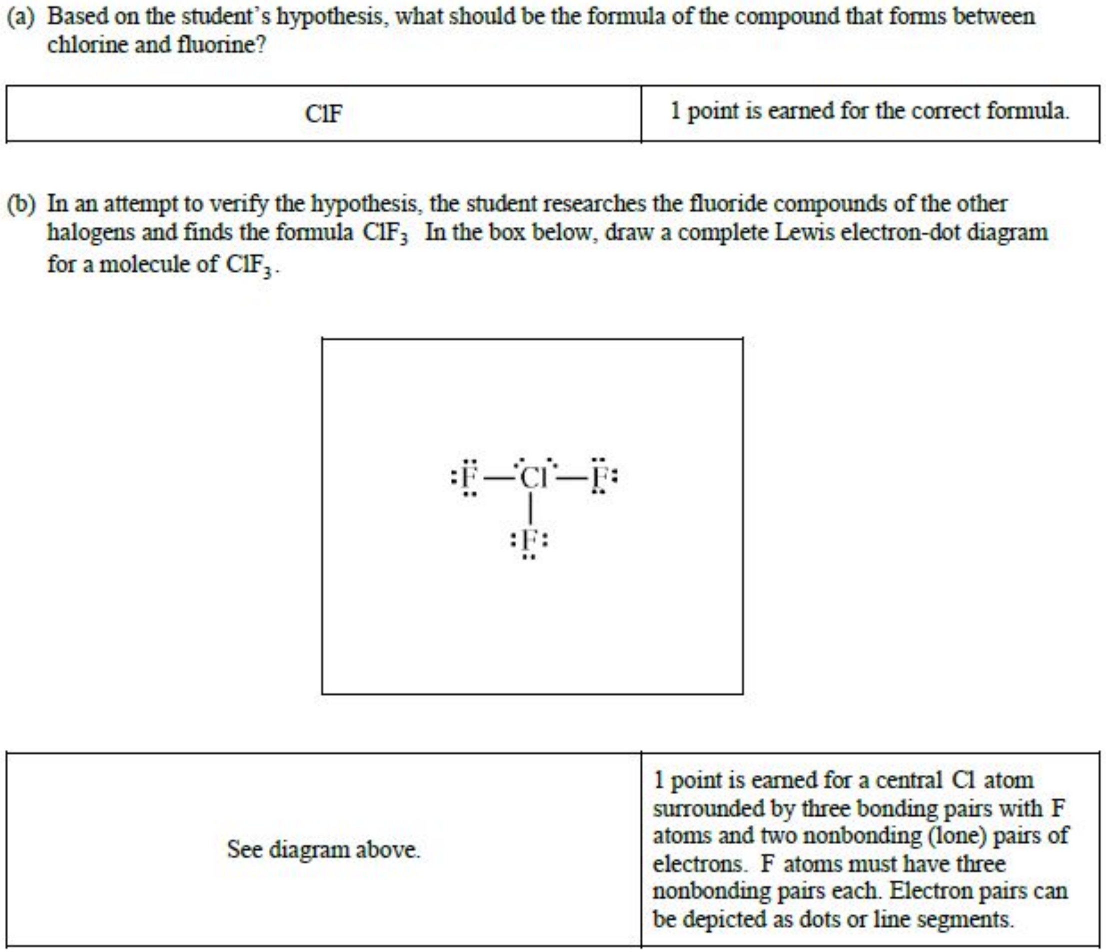
(c) Two possible geometric shapes for the ClF_3 molecule are trigonal planar and T-shaped. The student does some research and learns that the molecule has a dipole moment. Which of the two shapes is consistent with the fact that the ClF_3 molecule has a dipole moment? Justify your answer in terms of bond polarity and molecular structure.

In an attempt to resolve the existence of the ClF_3 molecule with the hypothesis stated above, the student researches the compounds that form between halogens and fluorine, and assembles the following list.

Halogen	Formula(s)
F	F_2
Cl	
Br	BrF, BrF_3, BrF_5
I	IF, IF_3, IF_5, IF_7

(d) Based on concepts of atomic structure and periodicity, propose a modification to the student's previous hypothesis to account for the compounds that form between halogens and fluorine.

2014 IPE #5 Scoring Guidelines and Things to Notice



(a) Based on the student's hypothesis, what should be the formula of the compound that forms between chlorine and fluorine?

ClF	1 point is earned for the correct formula.

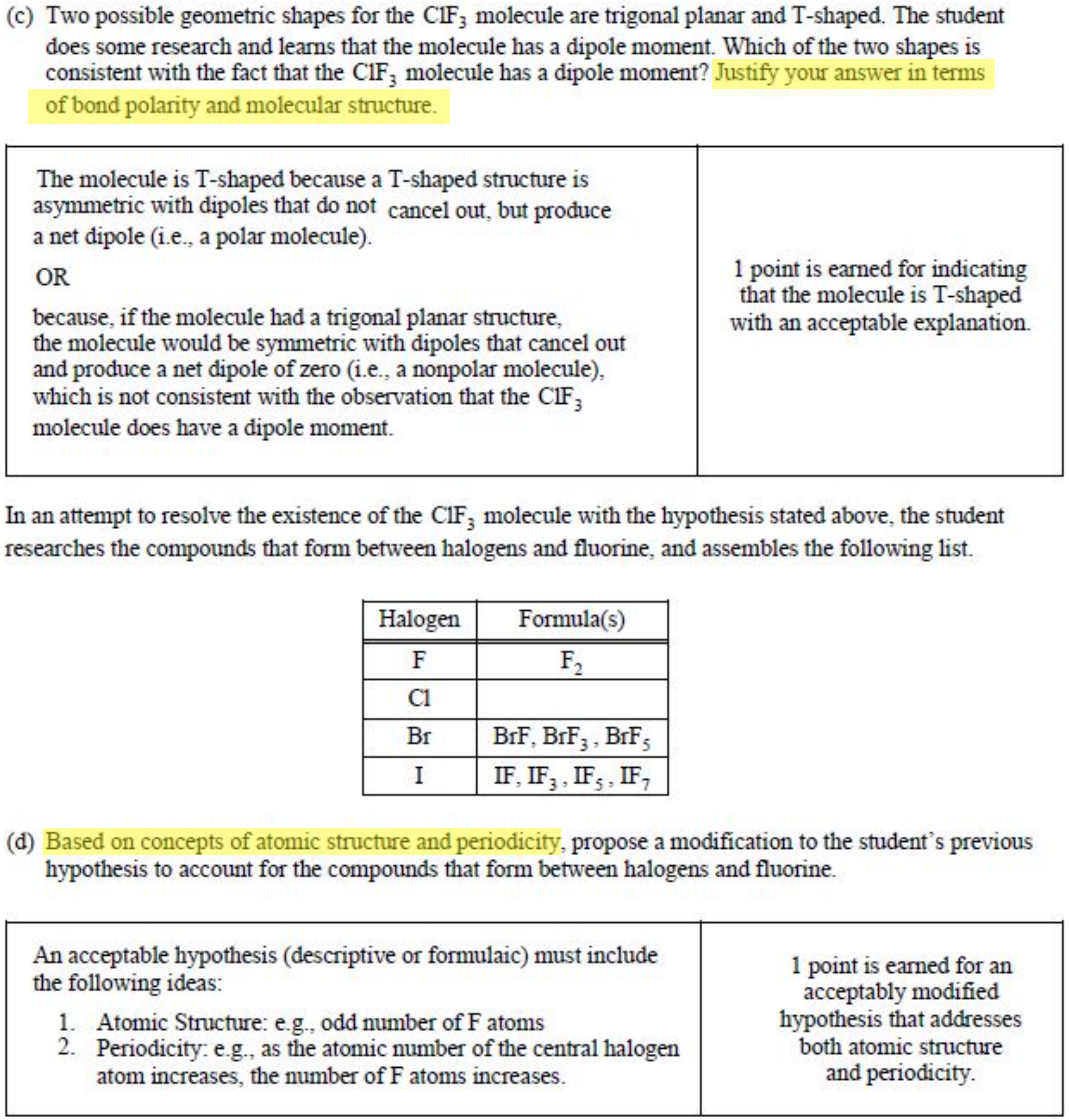
(b) In an attempt to verify the hypothesis, the student researches the fluoride compounds of the other halogens and finds the formula ClF_3 In the box below, draw a complete Lewis electron-dot diagram for a molecule of ClF_3.

See diagram above.	1 point is earned for a central Cl atom surrounded by three bonding pairs with F atoms and two nonbonding (lone) pairs of electrons. F atoms must have three nonbonding pairs each. Electron pairs can be depicted as dots or line segments.

- Be sure that your handwriting shows clearly that this is ClF with correct capitalization and order of the atoms

- Be sure that you clearly denote the 3 bonds between the Cl and the 3 F atoms and that you fully complete the 3 lone pairs around EACH F atom and the 2 lone pairs on the Cl

2014 IPE #5 Scoring Guidelines and Things to Notice (cont.)



(c) Two possible geometric shapes for the ClF_3 molecule are trigonal planar and T-shaped. The student does some research and learns that the molecule has a dipole moment. Which of the two shapes is consistent with the fact that the ClF_3 molecule has a dipole moment? Justify your answer in terms of bond polarity and molecular structure.

The molecule is T-shaped because a T-shaped structure is asymmetric with dipoles that do not cancel out, but produce a net dipole (i.e., a polar molecule). OR because, if the molecule had a trigonal planar structure, the molecule would be symmetric with dipoles that cancel out and produce a net dipole of zero (i.e., a nonpolar molecule), which is not consistent with the observation that the ClF_3 molecule does have a dipole moment.	1 point is earned for indicating that the molecule is T-shaped with an acceptable explanation.

In an attempt to resolve the existence of the ClF_3 molecule with the hypothesis stated above, the student researches the compounds that form between halogens and fluorine, and assembles the following list.

Halogen	Formula(s)
F	F_2
Cl	
Br	BrF, BrF_3, BrF_5
I	IF, IF_3, IF_5, IF_7

(d) Based on concepts of atomic structure and periodicity, propose a modification to the student's previous hypothesis to account for the compounds that form between halogens and fluorine.

An acceptable hypothesis (descriptive or formulaic) must include the following ideas: 1. Atomic Structure: e.g., odd number of F atoms 2. Periodicity: e.g., as the atomic number of the central halogen atom increases, the number of F atoms increases.	1 point is earned for an acceptably modified hypothesis that addresses both atomic structure and periodicity.

- Note that just saying "T Shaped" would not earn the point here – the correct geometry AND the justification are both needed
- The prompt says "in terms of bond polarity and molecular structure" – in addition to the geometry, the dipoles must be referenced

- The prompt says "based on concepts of atomic structure and periodicity" – both must be referenced to earn this point

Unit 3: Intermolecular Forces and Properties

Write This…	…Not That!	Rationale
Hydrogen bonding, dipole-dipole, London dispersion forces, etc. when asked to identify intermolecular forces	Ionic bonds, covalent bonds, metallic bonds when asked to identify intermolecular forces	Intermolecular forces are attractions between molecules; bonds are intramolecular forces (within molecules)
Discussion of ALL intermolecular forces when prompted to do so	Neglecting IMFs that may be weaker	If asked to state all IMFs, all points will not be earned if some of the IMFs are not stated (ref. 2018 #4a and 2019 #2c)
"Has hydrogen bonds between the molecules"	"Has hydrogen bonds"	Is unambiguous - Shows that you understand hydrogen bonds are not actually bonds
Electrical conductivity is a property of an ionic solution due to the charges on the dissociated ions	Electrical conductivity is due to the ionic precipitate, electrical conductivity is due to the water	Conductivity is due to the ability of a ion to carry charge; precipitate would not influence in solid form; pure water is non-conductive, (ref. 2019 #3e)
"Overcome intermolecular forces"	"break up" a solid/liquid, break covalent bonds	IMFs should be used to justify phase changes
Ion interactions when discussing ionic compounds	LDF's when discussing ionic compounds	Ionic compounds have ions with whole charges, which dominate interactions
"Coulombic attraction"	"Opposites attract"	State the actual reason not the memory aid
Describe the process of overcoming intermolecular forces/polarity	"Like dissolves like"	State the actual reason not the memory aid
Identify specific intermolecular forces at play	"stronger intermolecular forces"	Shows your understanding of the particulate-level chemistry

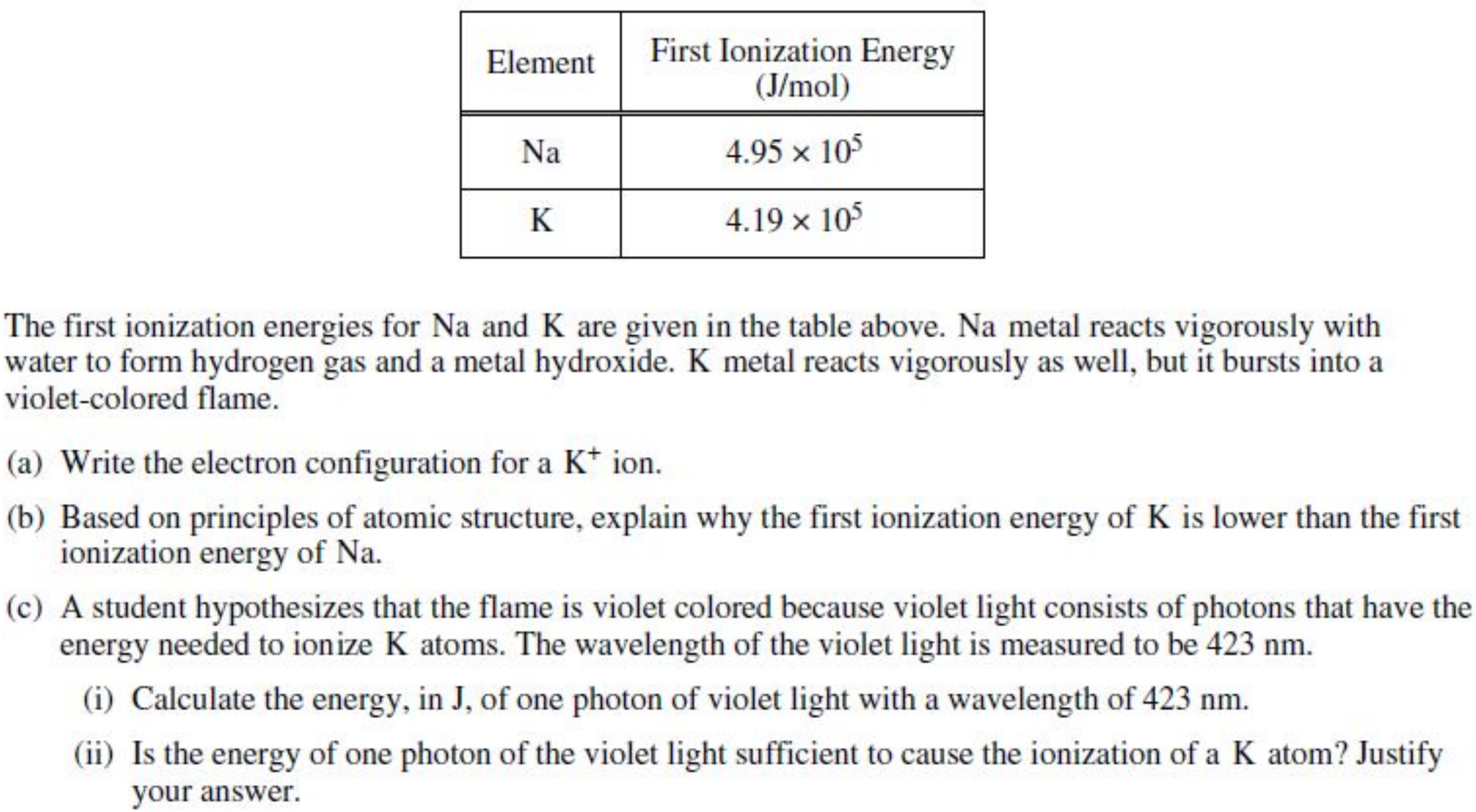
Unit 3: Intermolecular Forces and Properties (cont.)

Write This…	…Not That!	Rationale
Recognizing the difference in number of hydrogen bonding sites when comparing physical properties	Treating all species that form any amount of hydrogen bonds the same	The number of available hydrogen bonding sites impacts the physical properties (Ref 2022 #4b)
LDFs increase with an increasing number of electrons and therefore polarizability	LDFs increase with increasing size/mass	Increased number of electrons in an atom is what increases LDF; increased size is not the reason for increased strength of LDF
Intermolecular forces in discussing physical properties (MP, BP, solubility, etc): "Stronger intermolecular forces increase boiling point"	Intramolecular forces ("bonds") in discussing physical properties: "Stronger covalent bonds increase boiling point"	Bonds are not broken and so intramolecular forces are not the determining factors for physical properties (phase changes, solubility) (ref. 2018 #4a, 2019 #2c, 2022 #4b)
Pressure is caused by the collision of gas particles with the walls of a container.	Pressure is caused by the collision of gas particles.	Unclear wording – implies pressure is caused by gas particles colliding with each other not with the container (ref. 2019 #4c)
Use R value with corresponding units to those used in work (and correctly report final unit)	R value with mismatched units	Units used in Ideal Gas Law must match units on the R value (ref. 2018 #4b and 2019 #2d)
Comparison of R_f values in chromatography	Comparison of absolute height of spots on chromatograms	Take into account a difference in the distance the solvent front travelled between different chromatograms (ref. 2017 #4)
Discussion of intermolecular forces between analyte molecules and stationary/mobile phases	Repulsions between analyte molecules and stationary/mobile phases	The movement in chromatography is determined by the attraction for the stationary/mobile phase (ref. 2017 #4)
"Solution" when an ionic compound is dissolved in water	"Liquid" instead of solution	An ionic compound dissolved in water is a solution, not a liquid (the word liquid indicates a molten compound) (ref. 2019 #3e)

Unit 3: Intermolecular Forces and Properties (cont.)

Write This…	…Not That!	Rationale
Particle view diagrams with ions and polar molecules orientated in the correct direction relative to each other	Incorrectly oriented dipoles	Drawings must demonstrate understanding of interactions at the molecular level (ex. 2015 #4)
Solutions are prepared using volumetric flasks (most often), or most precise glassware provided in prompt	Solutions are prepared in beakers or graduated cylinders	Volumetric flasks are designed to make precise solutions and are only marked at 1 volume, they are filled so the bottom of the meniscus rests on the calibration mark after the solid has been completely dissolved (Ref. 2021 #3e, 2022 #3c)

Unit 3 Practice - 2016 IPE #5



Element	First Ionization Energy (J/mol)
Na	4.95×10^5
K	4.19×10^5

The first ionization energies for Na and K are given in the table above. Na metal reacts vigorously with water to form hydrogen gas and a metal hydroxide. K metal reacts vigorously as well, but it bursts into a violet-colored flame.

(a) Write the electron configuration for a K^+ ion.

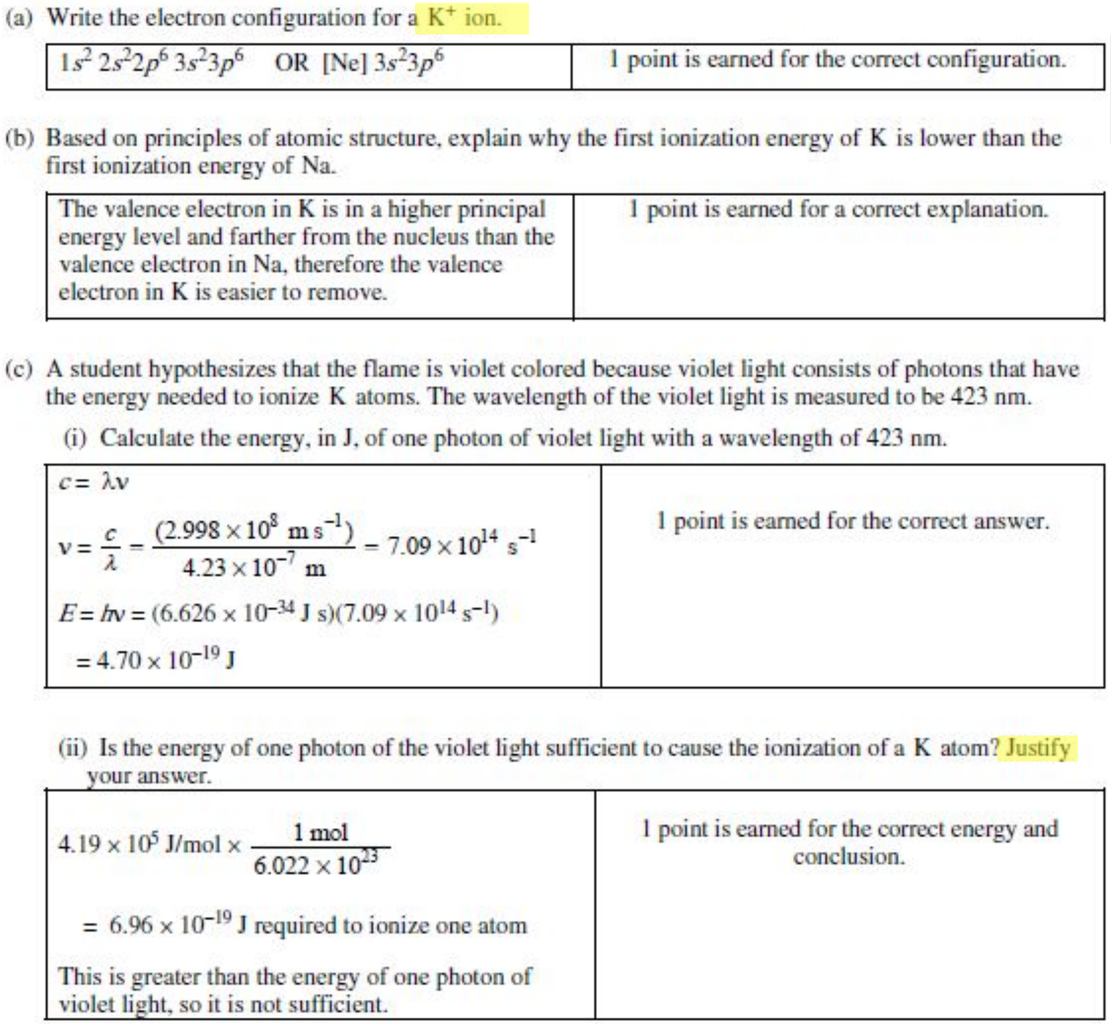
(b) Based on principles of atomic structure, explain why the first ionization energy of K is lower than the first ionization energy of Na.

(c) A student hypothesizes that the flame is violet colored because violet light consists of photons that have the energy needed to ionize K atoms. The wavelength of the violet light is measured to be 423 nm.

  (i) Calculate the energy, in J, of one photon of violet light with a wavelength of 423 nm.

  (ii) Is the energy of one photon of the violet light sufficient to cause the ionization of a K atom? Justify your answer.

2016 IPE #5 Scoring Guidelines and things to notice



(a) Write the electron configuration for a K^+ ion.

$1s^2\,2s^22p^6\,3s^23p^6$ OR [Ne] $3s^23p^6$	1 point is earned for the correct configuration.

(b) Based on principles of atomic structure, explain why the first ionization energy of K is lower than the first ionization energy of Na.

The valence electron in K is in a higher principal energy level and farther from the nucleus than the valence electron in Na, therefore the valence electron in K is easier to remove.	1 point is earned for a correct explanation.

(c) A student hypothesizes that the flame is violet colored because violet light consists of photons that have the energy needed to ionize K atoms. The wavelength of the violet light is measured to be 423 nm.

(i) Calculate the energy, in J, of one photon of violet light with a wavelength of 423 nm.

$c = \lambda\nu$ $\nu = \frac{c}{\lambda} = \frac{(2.998\times10^{8}\ \text{m s}^{-1})}{4.23\times10^{-7}\ \text{m}} = 7.09\times10^{14}\ \text{s}^{-1}$ $E = h\nu = (6.626\times10^{-34}\ \text{J s})(7.09\times10^{14}\ \text{s}^{-1})$ $= 4.70\times10^{-19}\ \text{J}$	1 point is earned for the correct answer.

(ii) Is the energy of one photon of the violet light sufficient to cause the ionization of a K atom? Justify your answer.

$4.19\times10^{5}\ \text{J/mol}\times\frac{1\ \text{mol}}{6.022\times10^{23}}$ $= 6.96\times10^{-19}$ J required to ionize one atom This is greater than the energy of one photon of violet light, so it is not sufficient.	1 point is earned for the correct energy and conclusion.

- Because this is K+, the valence electron is absent

- Both K and Na are mentioned, by using their symbol/name, and a comparison between the two is made

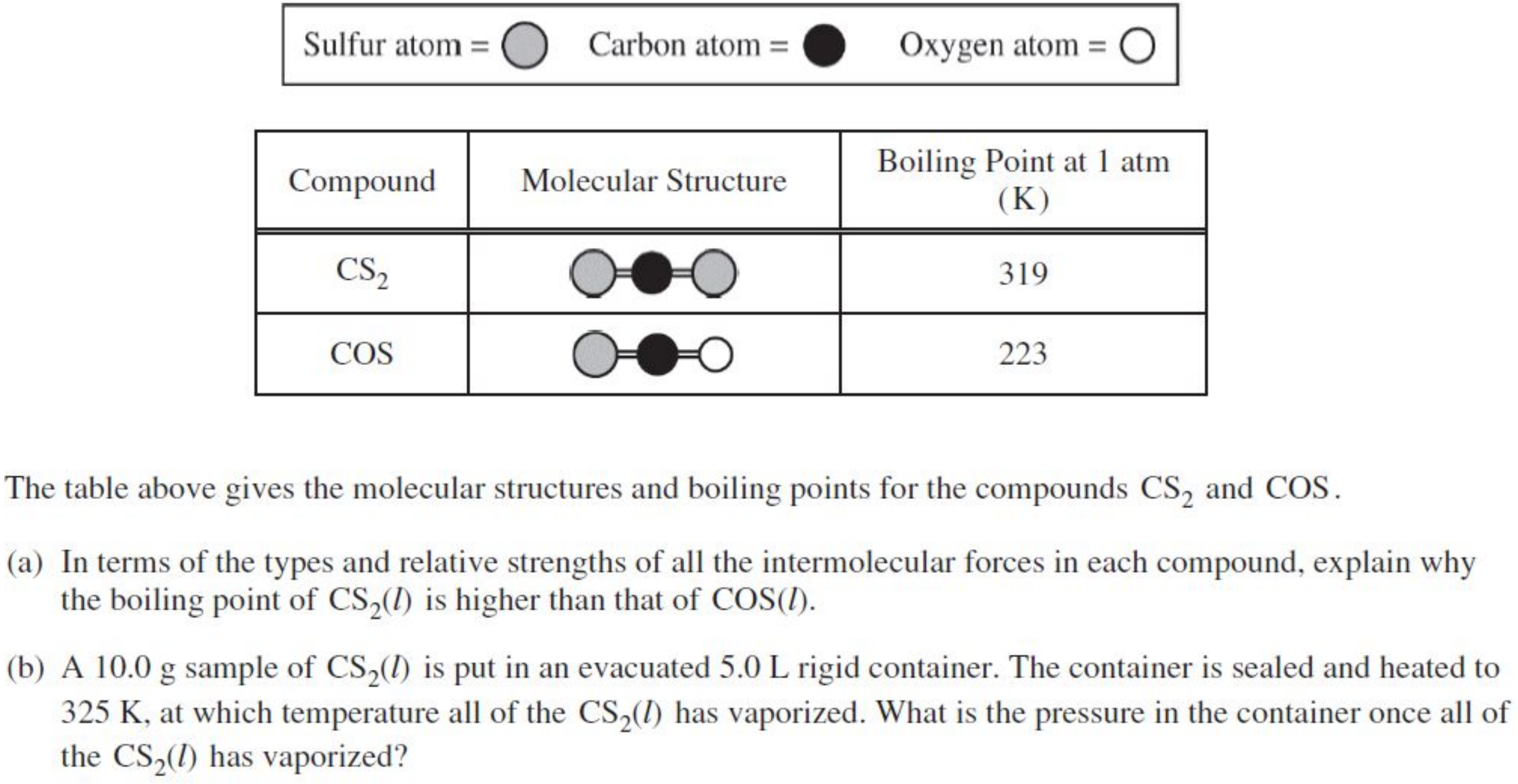
- Units are noted in the work so that it is easy to follow
- Correct units and sig figs are used – while not required to earn this particular point, they are often required

- Units are noted in the work so that it is easy to follow
- Notice that the math alone would not earn the point – the correct energy AND the application of the calculation to the conclusion are necessary

Unit 4: Chemical Reactions

Write This…	…Not That!	Rationale
Net ionic equations only containing species that change	Aqueous ionic compounds in their undissociated form, spectator ions	Including these is not a net ionic, it's a molecular or complete ionic
Polyatomic ions that are shown as a compound with the correct charge in solution	Polyatomic ions that are broken down into elemental ions in solution	Polyatomic ions themselves do not dissociate in solution, they only dissociate from the other ion in an ionic compound
Net ionic equations with correct species, ionic charges and stoichiometric coefficients	Net ionic equations that contain incorrect formulas or ions without associated charges or that are not stoichiometrically balanced	Net ionic equations must correctly represent the ions and other species (ref. 2018 #6a, 2019 #3a, 2021 #1di)
Determination of the concentration of an analyte in a titration that takes into account the stoichiometry of the reaction	Applying $M_1V_1=M_2V_2$ as a blanket method for determining concentration at an end point if the stoichiometry is not 1:1	While acid-base titrations are often 1:1, not all titrations (especially REDOX titrations) follow this stoichiometry; in situations that are not 1:1, the stoichiometric ratios must be accounted for in calculations (ref. 2018 #3e)
Justification of whether a species is oxidized/reduced by referencing oxidation numbers	A justification of oxidation/reduction that uses charge on an ion	Oxidation numbers are assigned to individual atoms in the reaction, and they are not automatically the same as the charge in a polyatomic ion (ref. 2019 #7a, 2022 #2a)
Particle view diagrams that pay respect to stoichiometric ratios	Ignoring stoichiometry in particle views	Must show ions dissociated with the correct ratios relative to the molecular formula/reaction that may be at play/limiting and excess reagents (ref. 2018 #2a, 2019 #3b, 2023 #7a)

Unit 3-4 Practice – 2018 FRQ #4



Sulfur atom = ◍ Carbon atom = ● Oxygen atom = ○

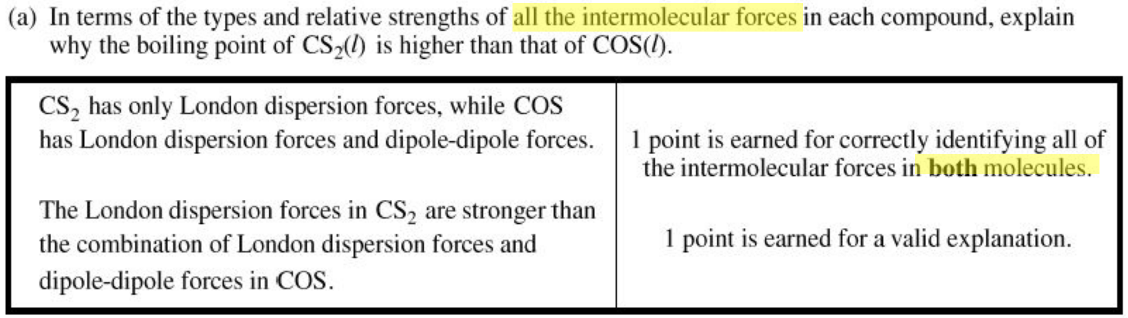
Compound	Molecular Structure	Boiling Point at 1 atm (K)
CS_2	◍=●=◍	319
COS	◍=●=○	223

The table above gives the molecular structures and boiling points for the compounds CS_2 and COS.

(a) In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of $CS_2(l)$ is higher than that of $COS(l)$.

(b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

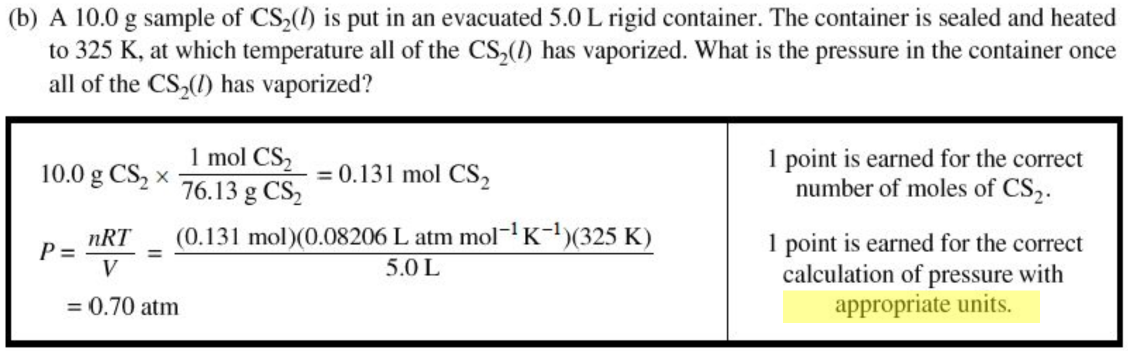
2018 FRQ #4 Scoring Guidelines and Things to Notice



(a) In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of $CS_2(l)$ is higher than that of $COS(l)$.

CS_2 has only London dispersion forces, while COS has London dispersion forces and dipole-dipole forces. The London dispersion forces in CS_2 are stronger than the combination of London dispersion forces and dipole-dipole forces in COS.	1 point is earned for correctly identifying all of the intermolecular forces in **both** molecules. 1 point is earned for a valid explanation.

- Prompt states ALL intermolecular forces; first point is not earned without saying all IMFs for both molecules
- In the explanation discuss the CS_2 relative to the COS – your answer should match the prompt



(b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

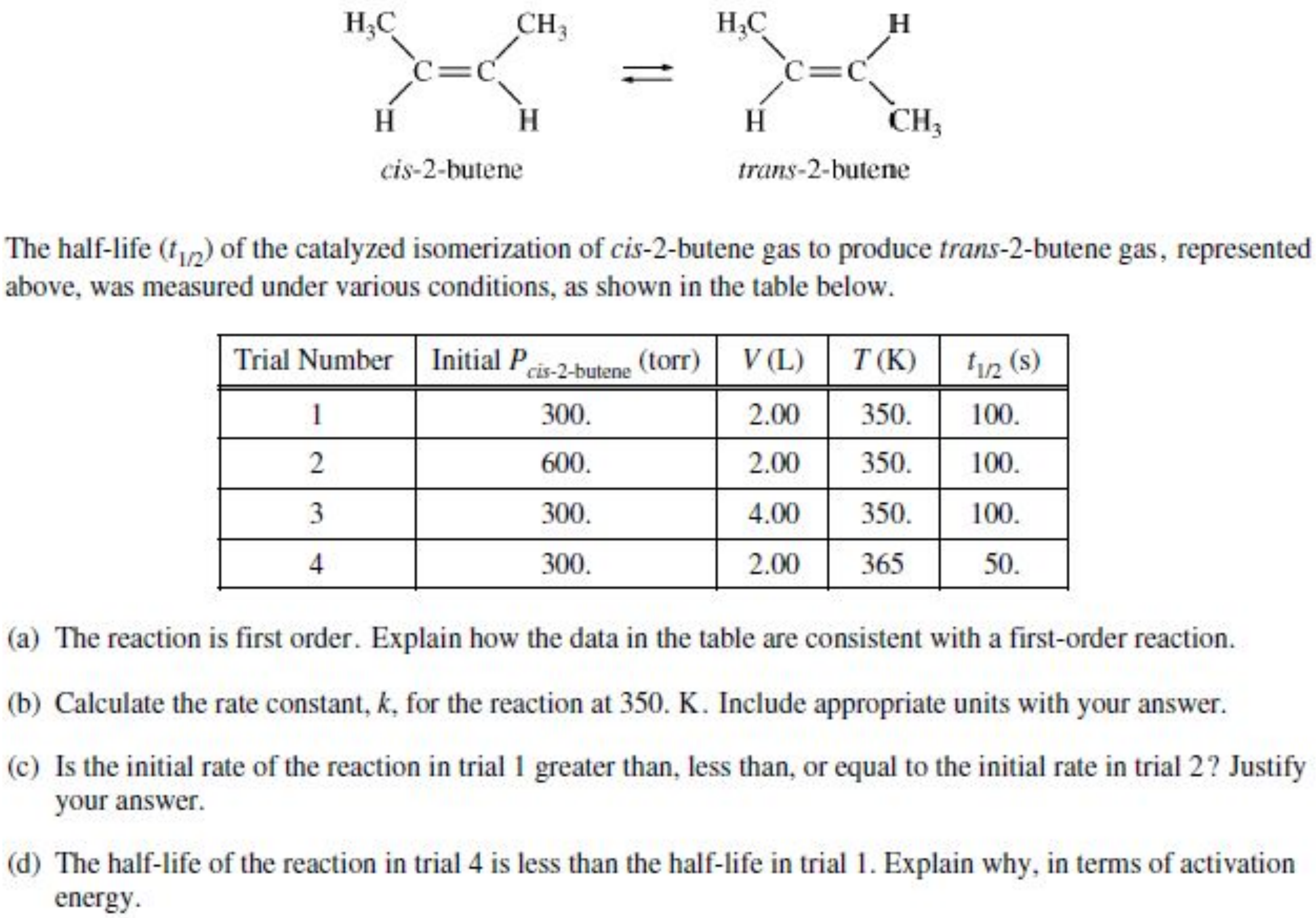
$10.0 \text{ g } CS_2 \times \frac{1 \text{ mol } CS_2}{76.13 \text{ g } CS_2} = 0.131 \text{ mol } CS_2$	1 point is earned for the correct number of moles of CS_2.
$P = \frac{nRT}{V} = \frac{(0.131 \text{ mol})(0.08206 \text{ L atm mol}^{-1} \text{K}^{-1})(325 \text{ K})}{5.0 \text{ L}}$ $= 0.70 \text{ atm}$	1 point is earned for the correct calculation of pressure with appropriate units.

- The point could be earned even if you combined the math into one entry in your calculator – units and labels are important so the reader can award you this implicit point
- The answer must include units to be awarded the second point

Unit 5: Kinetics

Write This…	…Not That!	Rationale
A rate law based only on reactants	A rate law that includes products	Rate laws are based only on reactants
A rate law that includes the rate constant k as part of it	A rate law without k being included	Incomplete rate law if k is not included
Value of k with units	Value of k without units	Units required to earn point (Ref 2022 #5a)
Specific parts of the molecules that must collide in order for the reaction to occur	"Collision must occur in the correct orientation"	Show your understanding of the collision theory
A validation of a proposed mechanism by showing that the rate law matches the slow (rate-determining step) and the mechanism matching the overall stoichiometry for the reaction.	A justification of a mechanism just by saying "it matches the rate law" or "the intermediates cancel to give the overall process".	The rate law must be discussed as matching the rate-determining step, and the overall stoichiometry should always match for any proposed mechanism – an understanding of the rate determining step must be demonstrated. (ref. 2019 #6b, 2022 #5b)
Recognizing that the half-life is constant for a first-order reaction	Failing to recognize that half-life is constant for a first order reaction	Half life is constant for first order reactions only and can be used to identify a first order of a reaction if given time versus concentration data

Unit 5 Practice – 2014 IPE #7



cis-2-butene

trans-2-butene

The half-life ($t_{1/2}$) of the catalyzed isomerization of *cis*-2-butene gas to produce *trans*-2-butene gas, represented above, was measured under various conditions, as shown in the table below.

Trial Number	Initial $P_{cis\text{-}2\text{-}butene}$ (torr)	V (L)	T (K)	$t_{1/2}$ (s)
1	300.	2.00	350.	100.
2	600.	2.00	350.	100.
3	300.	4.00	350.	100.
4	300.	2.00	365	50.

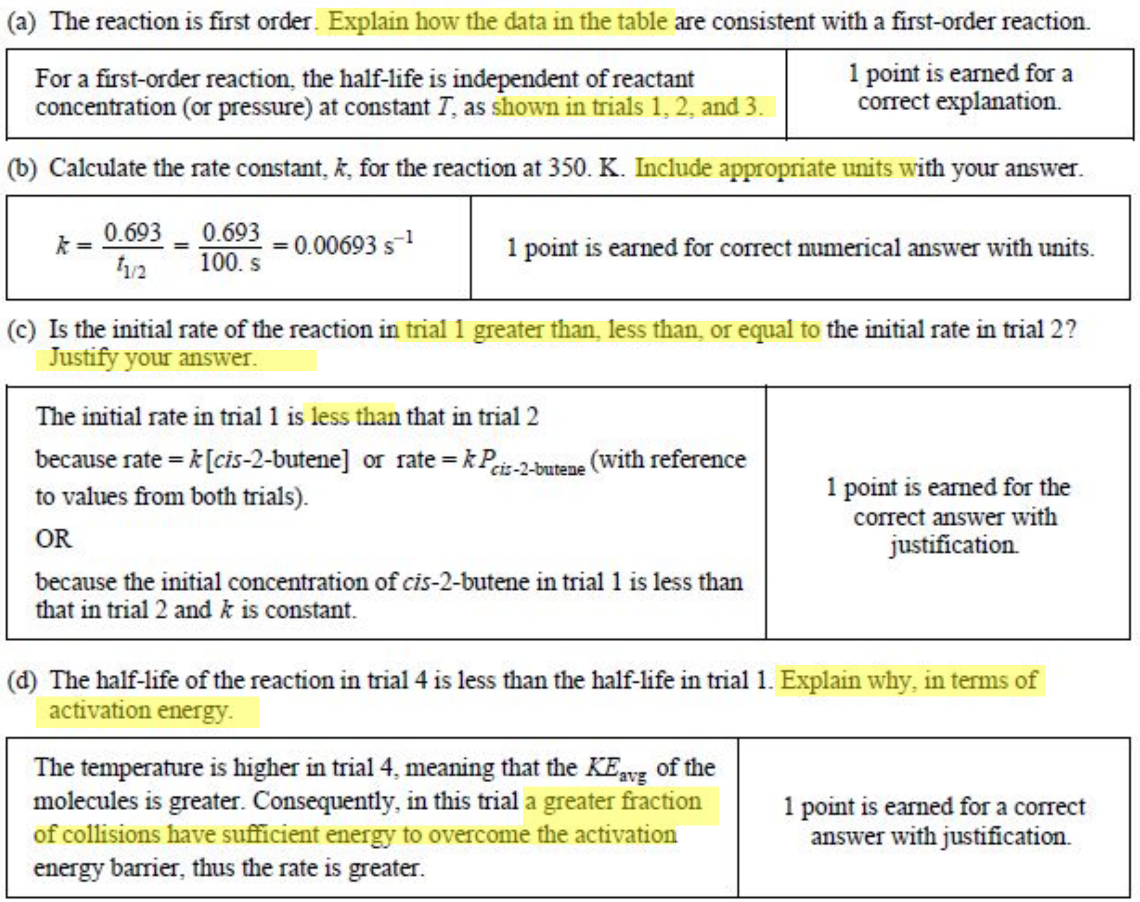
(a) The reaction is first order. Explain how the data in the table are consistent with a first-order reaction.

(b) Calculate the rate constant, k, for the reaction at 350. K. Include appropriate units with your answer.

(c) Is the initial rate of the reaction in trial 1 greater than, less than, or equal to the initial rate in trial 2? Justify your answer.

(d) The half-life of the reaction in trial 4 is less than the half-life in trial 1. Explain why, in terms of activation energy.

2014 IPE #7 Scoring Guidelines and Things to Notice



(a) The reaction is first order. Explain how the data in the table are consistent with a first-order reaction.

For a first-order reaction, the half-life is independent of reactant concentration (or pressure) at constant T, as shown in trials 1, 2, and 3.	1 point is earned for a correct explanation.

(b) Calculate the rate constant, k, for the reaction at 350. K. Include appropriate units with your answer.

$k = \frac{0.693}{t_{1/2}} = \frac{0.693}{100.\ \text{s}} = 0.00693\ \text{s}^{-1}$	1 point is earned for correct numerical answer with units.

(c) Is the initial rate of the reaction in trial 1 greater than, less than, or equal to the initial rate in trial 2? Justify your answer.

The initial rate in trial 1 is less than that in trial 2 because rate = k[*cis*-2-butene] or rate = $k P_{cis\text{-2-butene}}$ (with reference to values from both trials). OR because the initial concentration of *cis*-2-butene in trial 1 is less than that in trial 2 and k is constant.	1 point is earned for the correct answer with justification.

(d) The half-life of the reaction in trial 4 is less than the half-life in trial 1. Explain why, in terms of activation energy.

The temperature is higher in trial 4, meaning that the KE_{avg} of the molecules is greater. Consequently, in this trial a greater fraction of collisions have sufficient energy to overcome the activation energy barrier, thus the rate is greater.	1 point is earned for a correct answer with justification.

- The answer needs to reference the data table so that it meets the requirements in the prompt.

- The answer must include units to be awarded the point.

- First answer the question by choosing one of the listed options (for trial 1).
- Then justify
- Both parts must be included in order for the point to be earned

- The answer must be justified relative to activation energy – just stating the KE is greater will not be enough.

Unit 6: Thermodynamics

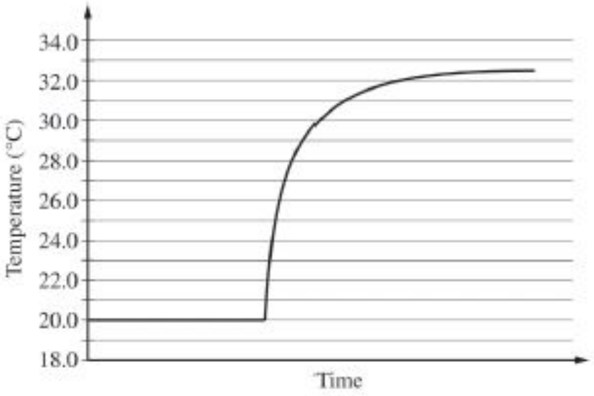
Write This…	…Not That!	Rationale
"Thermodynamically favorable", "thermodynamically feasible"	"Spontaneous"	Preferred AP language
Values with correct signs	Values with incorrect signs	Necessary for correct calculations and determinations – watch signs based on bonds breaking/forming, heat flow in calorimetry indicated by temperature changes, signs that may change in application of Hess' Law, etc.
Changing the sign of q_{system} when using the value of q for surroundings	Using the q_{system} value for calculations involving the surroundings without changing the sign	$q_{system} = -q_{surroundings}$ (Ref. 2021 #3b)
Using values of q recognizing that it is the amount of energy absorbed/released during a thermodynamic change	Using values of q interchangeably as values of ΔH without taking the entire situation into account.	ΔH and q do not have identical meaning; ΔH is the enthalpy change for a reaction, q is the overall amount of heat exchanged ; Stoichiometric relationships, the component of the system being examined, etc. may influence how q should be manipulated to determine ΔH (ref. 2018 #1)
In using $q=mc\Delta T$ for solutions, using mass of ENTIRE solution for m	Using mass of only one component of solution	When using $q=mc\Delta T$, the mass of the entire system being examined must be used
Using both $q=mc\Delta T$ and heat of fusion/vaporation calculations for a situation in which a substance goes through both a phase change and a temperature change	Using only $q=mc\Delta T$ for a situation in which a substance goes through both a phase change and a temperature change	When a substance experiences a temperature change and a phase change, the two quantities of heat are calculated separately and summed (Ref 2022 #1c)

Unit 6: Thermodynamics (cont.)

Write This…	…Not That!	Rationale
Use a thermometer to measure temperature values, and then subtract to find ΔT	Use a thermometer to measure ΔT	A thermometer doesn't measure ΔT, it measures T values that can then be used to calculate ΔT (ref. 2019 #1e)
$\Delta H° = \Sigma$(enthalpies of bonds broken) $- \Sigma$(enthalpies of bonds formed) when calculating $\Delta H°_{rxn}$ from bond energies	$\Delta H°_{rxn} = \Delta H_{products} - \Delta H_{reactants}$ when calculating $\Delta H°_{rxn}$ from bond energies	Applying the wrong formula will give an incorrect sign for the $\Delta H°_{rxn}$ (ref. 2017 #2b)
Multiplying bond energy values by stoichiometric factors as well as number of bonds in a molecule when calculating ΔH from bond energies	Only using number of bonds in a single molecule without taking stoichiometric factors into account	Stoichiometry factors represent the number of molecules taking part in the reaction, so number of bonds in a single molecule must be multiplied by this coefficient (ref. 2019 #2g)

Unit 6 Practice – 2018 FRQ #1 (parts d-g)

The solutions, all originally at 20.0°C, are combined in an insulated calorimeter. The temperature of the reaction mixture is monitored, as shown in the graph below.



(d) According to the graph, what is the temperature change of the reaction mixture?

(e) The mass of the reaction mixture inside the calorimeter is 15.21 g.

- (i) Calculate the magnitude of the heat energy, in joules, that is released during the reaction. Assume that the specific heat of the reaction mixture is 3.94 J/(g·°C) and that the heat absorbed by the calorimeter is negligible.
- (ii) Using the balanced equation for the oxidation-reduction reaction and your answer to part (c), calculate the value of the enthalpy change of the reaction, ΔH°_{rxn}, in kJ/mol$_{rxn}$. Include the appropriate algebraic sign with your answer.

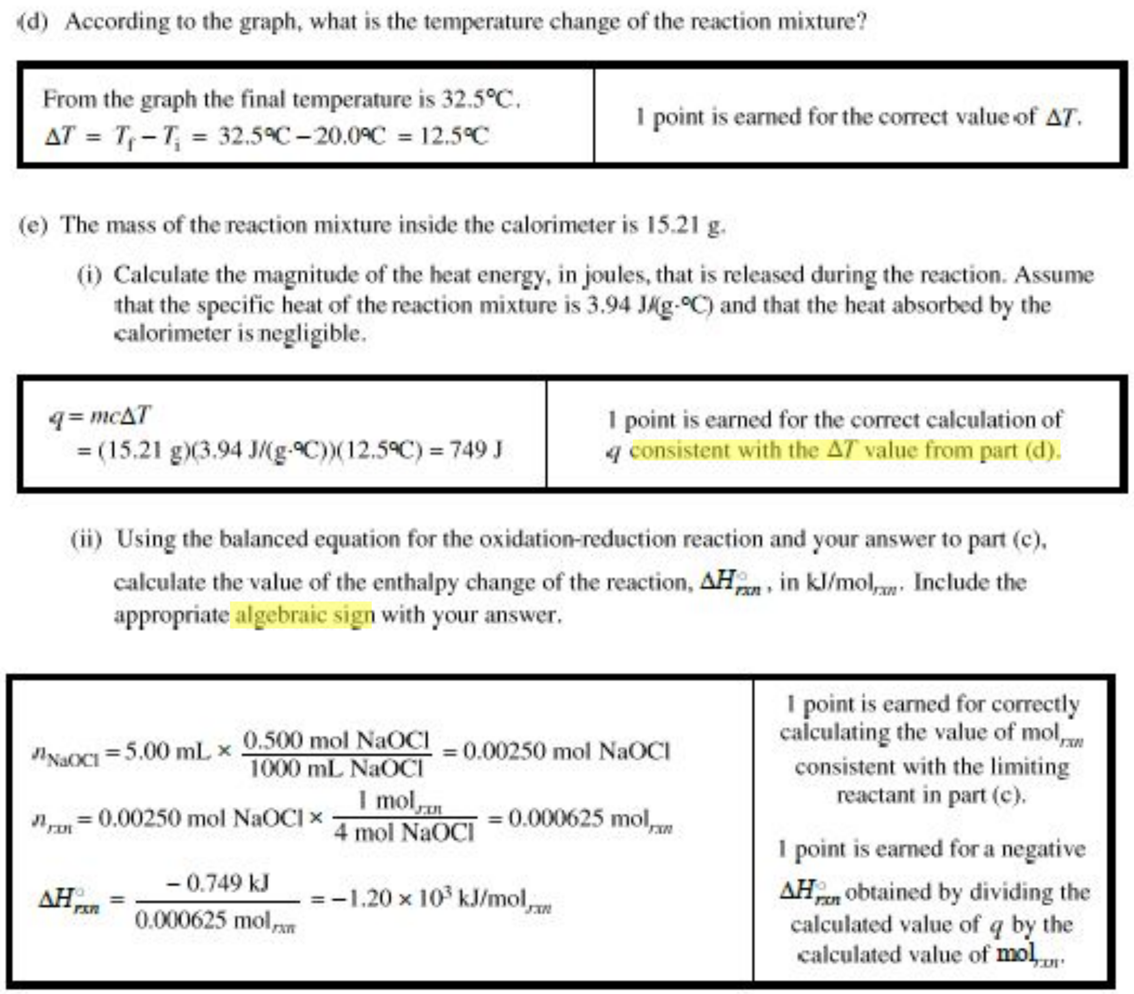
The student repeats the experiment, but this time doubling the volume of each of the reactants, as shown in the table below.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	10.0
$NaOCl(aq)$	0.500	10.0
$NaOH(aq)$	0.500	10.0

(f) The magnitude of the enthalpy change, ΔH°_{rxn}, in kJ/mol$_{rxn}$, calculated from the results of the second experiment is the same as the result calculated in part (e)(ii). Explain this result.

(g) Write the balanced net ionic equation for the given reaction.

2018 FRQ #1 Scoring Guidelines and Things to Notice



(d) According to the graph, what is the temperature change of the reaction mixture?

From the graph the final temperature is 32.5°C. $\Delta T = T_f - T_i = 32.5°\text{C} - 20.0°\text{C} = 12.5°\text{C}$	1 point is earned for the correct value of ΔT.

(e) The mass of the reaction mixture inside the calorimeter is 15.21 g.

(i) Calculate the magnitude of the heat energy, in joules, that is released during the reaction. Assume that the specific heat of the reaction mixture is 3.94 J/(g·°C) and that the heat absorbed by the calorimeter is negligible.

$q = mc\Delta T$ $= (15.21\text{ g})(3.94\text{ J/(g·°C)})(12.5°\text{C}) = 749\text{ J}$	1 point is earned for the correct calculation of q consistent with the ΔT value from part (d).

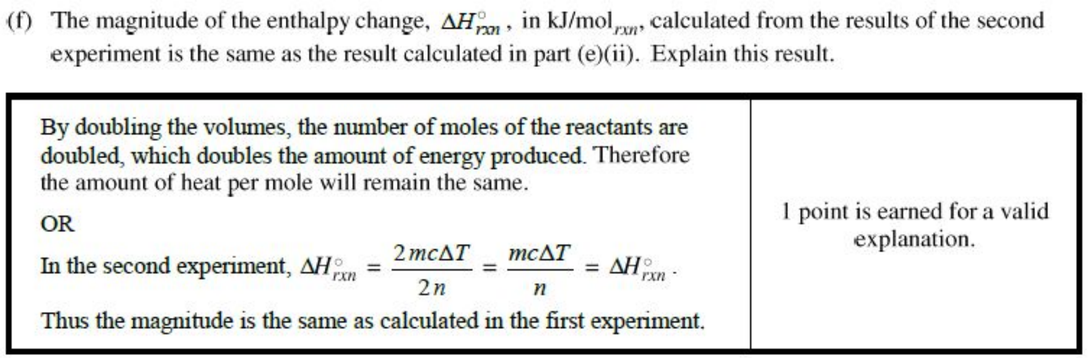
(ii) Using the balanced equation for the oxidation-reduction reaction and your answer to part (c), calculate the value of the enthalpy change of the reaction, ΔH°_{rxn}, in kJ/mol$_{rxn}$. Include the appropriate algebraic sign with your answer.

$n_{\text{NaOCl}} = 5.00\text{ mL} \times \frac{0.500\text{ mol NaOCl}}{1000\text{ mL NaOCl}} = 0.00250\text{ mol NaOCl}$ $n_{rxn} = 0.00250\text{ mol NaOCl} \times \frac{1\text{ mol}_{rxn}}{4\text{ mol NaOCl}} = 0.000625\text{ mol}_{rxn}$ $\Delta H^\circ_{rxn} = \frac{-0.749\text{ kJ}}{0.000625\text{ mol}_{rxn}} = -1.20 \times 10^3\text{ kJ/mol}_{rxn}$	1 point is earned for correctly calculating the value of mol$_{rxn}$ consistent with the limiting reactant in part (c). 1 point is earned for a negative ΔH°_{rxn} obtained by dividing the calculated value of q by the calculated value of mol$_{rxn}$.

- Notice that there is no double-jeopardy – a wrong value from part (d) used correctly here earns point

- Be sure work is represented so that all intermediate work can be recognized -even if you don’t stop to get an answer – so you can earn full points
- Missing negative sign would not earn the point
- Show work so that maximum points can be earned

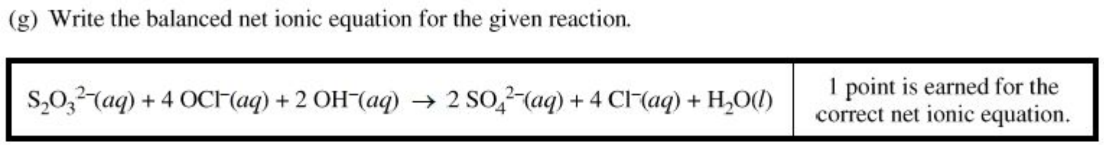
2018 FRQ #1 Scoring Guidelines and Things to Notice



(f) The magnitude of the enthalpy change, ΔH°_{rxn} , in kJ/mol$_{rxn}$, calculated from the results of the second experiment is the same as the result calculated in part (e)(ii). Explain this result.

By doubling the volumes, the number of moles of the reactants are doubled, which doubles the amount of energy produced. Therefore the amount of heat per mole will remain the same. OR In the second experiment, $\Delta H^\circ_{rxn} = \frac{2mc\Delta T}{2n} = \frac{mc\Delta T}{n} = \Delta H^\circ_{rxn}$. Thus the magnitude is the same as calculated in the first experiment.	1 point is earned for a valid explanation.

- Answer must be clear and easy to follow; also, both cause and effect are noted



(g) Write the balanced net ionic equation for the given reaction.

$S_2O_3^{2-}(aq) + 4\ OCl^-(aq) + 2\ OH^-(aq) \rightarrow 2\ SO_4^{2-}(aq) + 4\ Cl^-(aq) + H_2O(l)$	1 point is earned for the correct net ionic equation.

- Correct charges and stoichiometric factors must be included

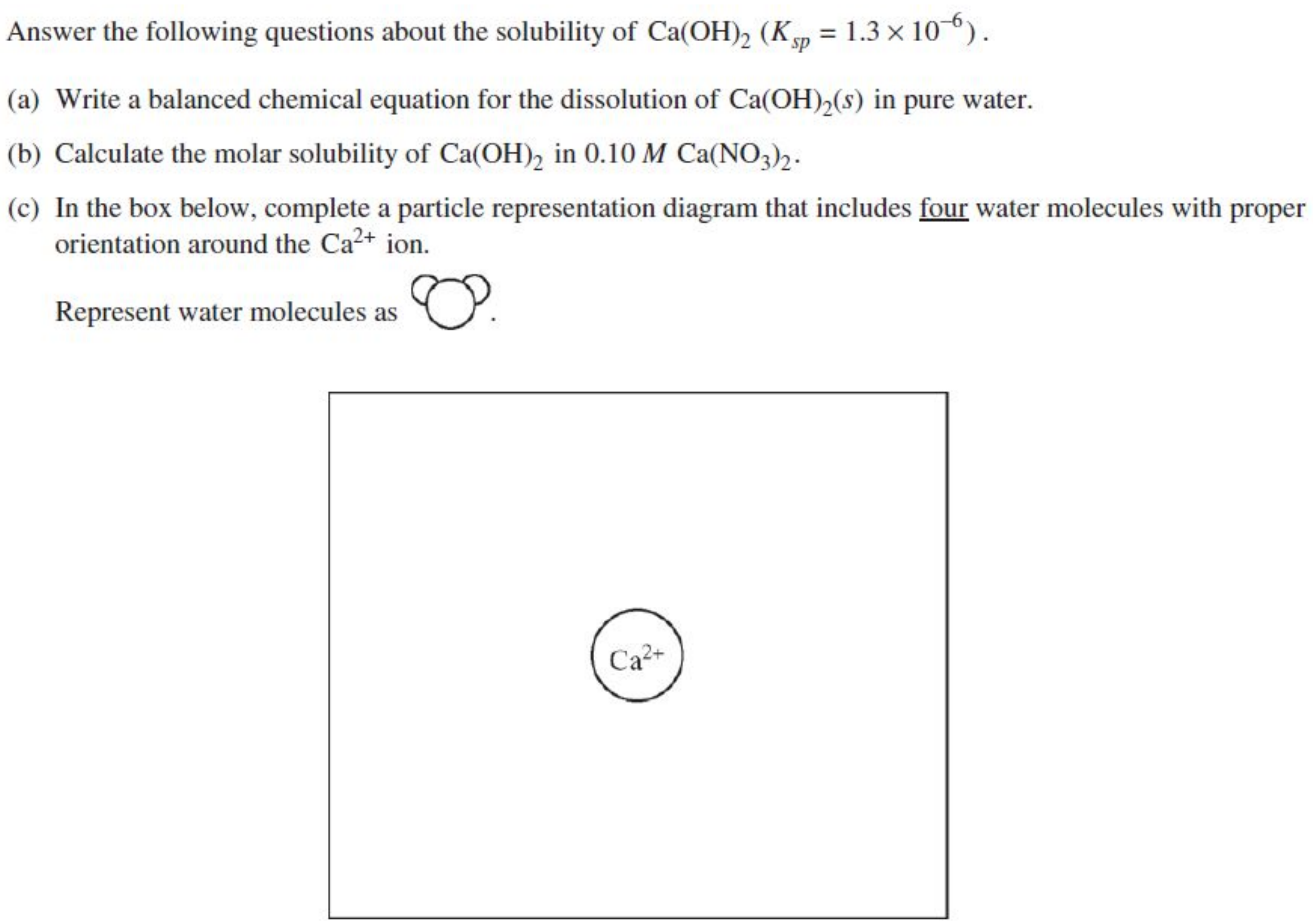
Unit 7: Equilibrium

Write This…	…Not That!	Rationale
Beginning K expressions with K=	Not including K= at the beginning of a K expression	K expressions must begin with K= (Ref 2021 #1a)
Correct formulas (including charges!) for all species in equilibrium expressions	Substitutions, abbreviations, chargeless ions, other shorthand that may work out in calculations but does not represent the correct species	Equilibrium expressions must be written formally when requested
K expressions that include only aqueous and gases species	K expressions that include solid and liquid species (including water)	Solids and liquids are not included in K expressions (Ref 2021 #1a)
In K_p expressions: $P_{species}$	In K_p expressions: [species]	Concentration (which is indicated by brackets around the species) is not used in K_p - partial pressures are
K expressions with EITHER concentration "[ ]" or partial pressures "P"	K expressions that include both concentration "[ ]" and partial pressures "P" in the same expression	Equilibrium expressions are written for either concentration values or partial pressure values, not both at the same time in a single expression (ref. 2019 #2e)
K without units	K with units	K is a unitless constant
"K is greater than 1, indicating that the products are present in a higher concentration and therefore equilibrium lies to the right"	"K is large"	Use specific values to demonstrate understanding about the meaning of K relative to the equilibrium position (ref. 2017 #2d)

Unit 7: Equilibrium (cont.)

Write This…	…Not That!	Rationale
"Proceeds"	"Shift" – if equilibrium has not yet been established (i.e. a precipitate has not yet been formed when evaluating K_{sp})	If equilibrium is not yet established, then it cannot "shift" – rxn will proceed in a certain direction until equilibrium is established
Calculations of K expressions that use concentrations/partial pressures at equilibrium	Calculations of K expressions that use initial concentrations/partial pressures	K values can only be calculated using equilibrium values; if initial values are given, an ICE table (or similar method) should be used to determine equilibrium values before calculating the K value (ref. 2018 #5b)
Using stoichiometric factors in ICE tables	Neglecting stoichiometry when calculating change in equilibrium scenarios	Stoichiometry ratios impact how much an initial value is changed during the establishment of equilibrium (ref. 2019 #2f)
"x has been assumed to be so small relative to the original concentrations that it can be ignored"	Nothing about why you ignore x to avoid quadratics	Show you understand why you are making the decision
Discussion of Q vs. K	"reduce the stress", or "due to Le Châtelier's Principle"	Preferred AP language-shows a deeper understanding of chemical principles (ref. 2018 #5c, 2022 #2g)
K_{sp} expressions that only contain the ions	K_{sp} expressions that contain or imply a species in the denominator	Solids and liquids are not included in equilibrium expressions
Answers that consider whether a new system has been created that will reach equilibrium or an established system at equilibrium is being disrupted	Assuming that all new conditions utilize Le Châtlier's Principle	There is a difference between stressing an established equilibrium (Q vs K and Le Chat discussion) versus creating a new system that utilizes the same reaction (K calculations/ICE tables) (ref. 2023 #7c)

Unit 7 Practice – 2015 FRQ #4



Answer the following questions about the solubility of $Ca(OH)_2$ ($K_{sp} = 1.3 \times 10^{-6}$).

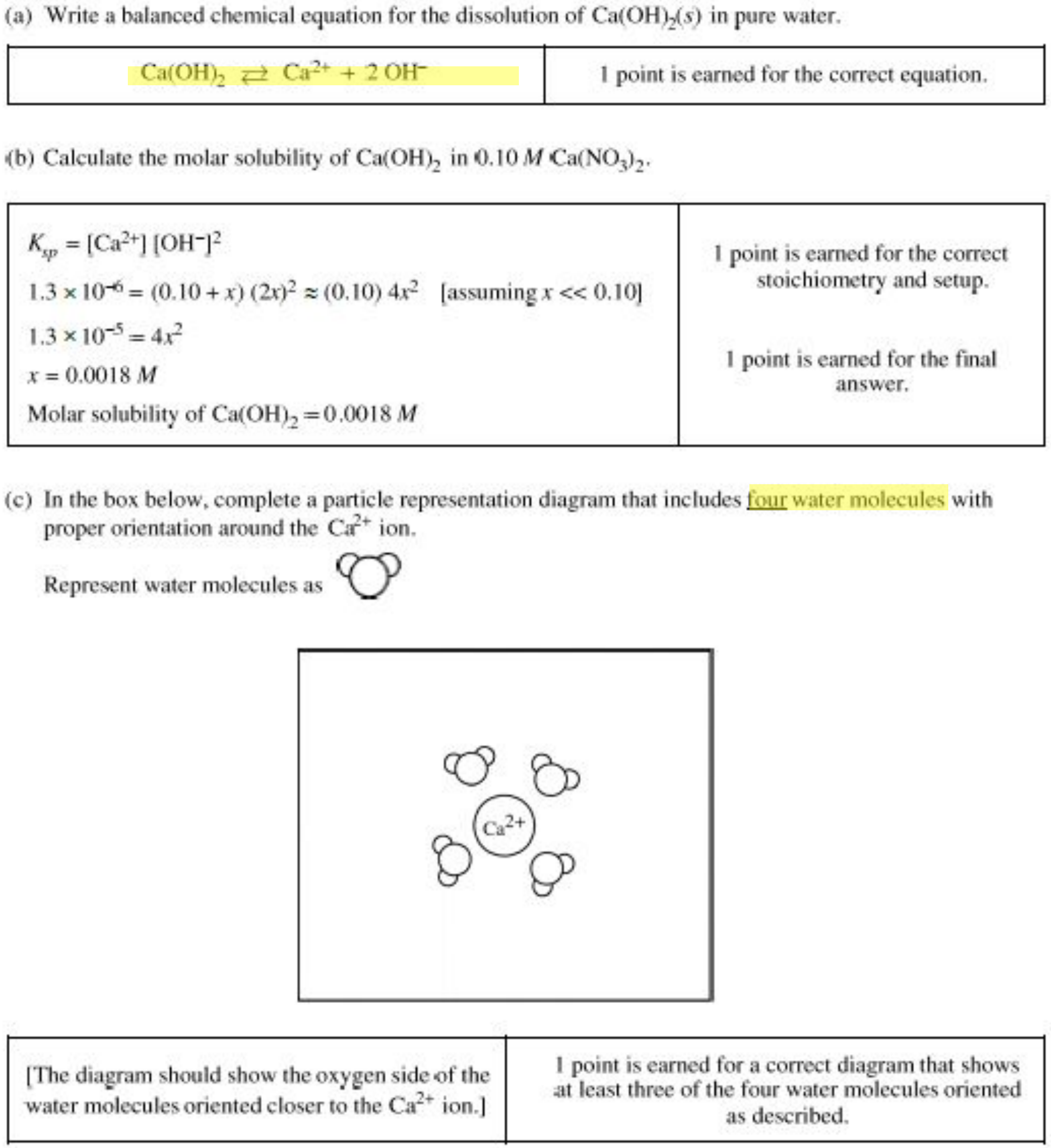
(a) Write a balanced chemical equation for the dissolution of $Ca(OH)_2(s)$ in pure water.

(b) Calculate the molar solubility of $Ca(OH)_2$ in 0.10 *M* $Ca(NO_3)_2$.

(c) In the box below, complete a particle representation diagram that includes <u>four</u> water molecules with proper orientation around the Ca^{2+} ion.

Represent water molecules as .

2015 FRQ #4 Scoring Guidelines and Things to Notice



(a) Write a balanced chemical equation for the dissolution of $Ca(OH)_2(s)$ in pure water.

$Ca(OH)_2 \rightleftarrows Ca^{2+} + 2\ OH^-$	1 point is earned for the correct equation.

(b) Calculate the molar solubility of $Ca(OH)_2$ in 0.10 *M* $Ca(NO_3)_2$.

$K_{sp} = [Ca^{2+}]\,[OH^-]^2$ $1.3 \times 10^{-6} = (0.10 + x)\ (2x)^2 \approx (0.10)\ 4x^2$ [assuming $x << 0.10$] $1.3 \times 10^{-5} = 4x^2$ $x = 0.0018\ M$ Molar solubility of $Ca(OH)_2 = 0.0018\ M$	1 point is earned for the correct stoichiometry and setup. 1 point is earned for the final answer.

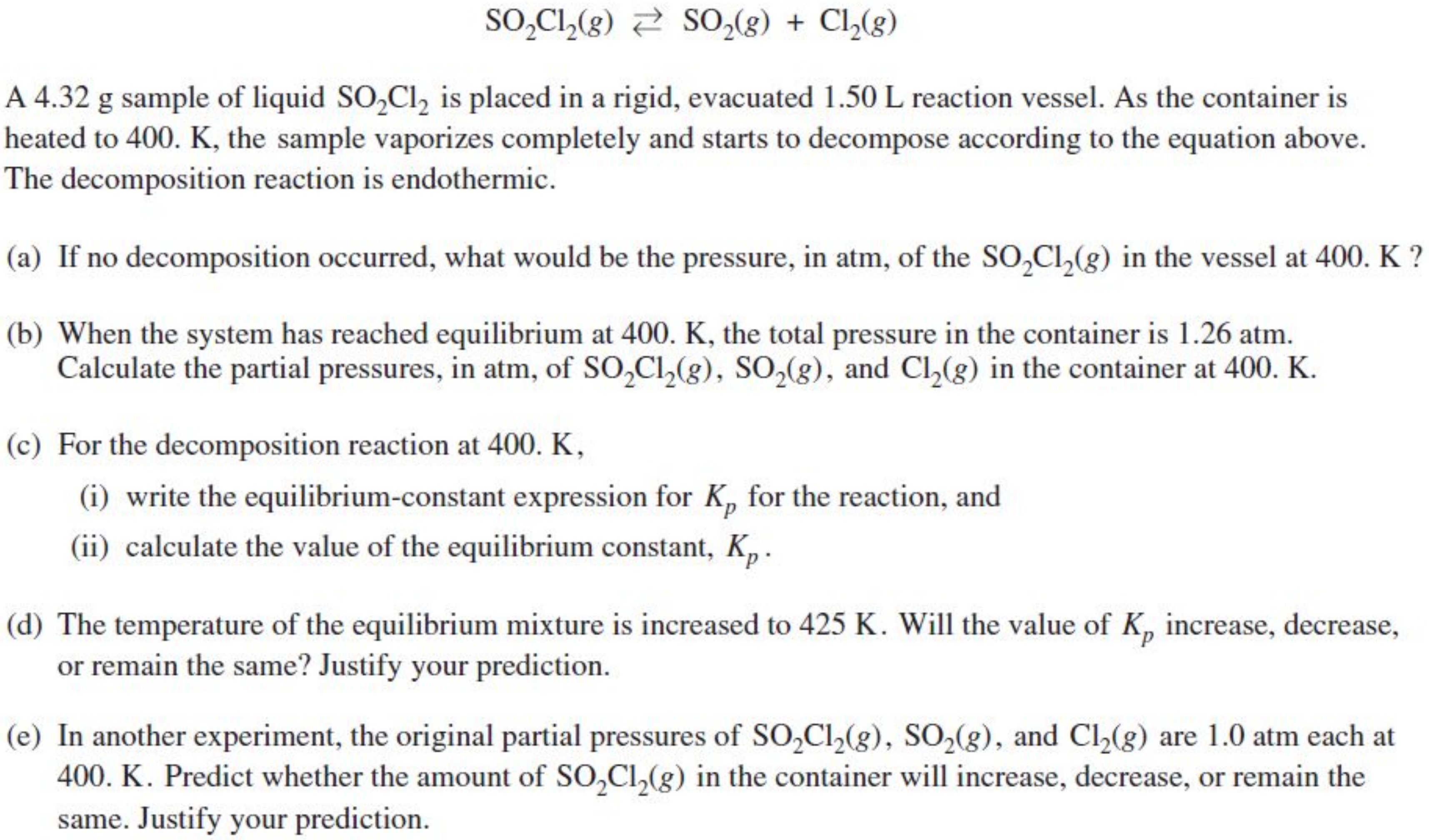
(c) In the box below, complete a particle representation diagram that includes four water molecules with proper orientation around the Ca^{2+} ion.

Represent water molecules as

[The diagram should show the oxygen side of the water molecules oriented closer to the Ca^{2+} ion.]	1 point is earned for a correct diagram that shows at least three of the four water molecules oriented as described.

- Correct stoichiometry and charges must be included to earn the point
- Show work so that maximum points can be earned – no work would not earn the first point
- Be sure to pay attention to direction in prompt

Unit 7 Practice – 2013 IPE #3



$$SO_2Cl_2(g) \rightleftarrows SO_2(g) + Cl_2(g)$$

A 4.32 g sample of liquid SO_2Cl_2 is placed in a rigid, evacuated 1.50 L reaction vessel. As the container is heated to 400. K, the sample vaporizes completely and starts to decompose according to the equation above. The decomposition reaction is endothermic.

(a) If no decomposition occurred, what would be the pressure, in atm, of the $SO_2Cl_2(g)$ in the vessel at 400. K ?

(b) When the system has reached equilibrium at 400. K, the total pressure in the container is 1.26 atm. Calculate the partial pressures, in atm, of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ in the container at 400. K.

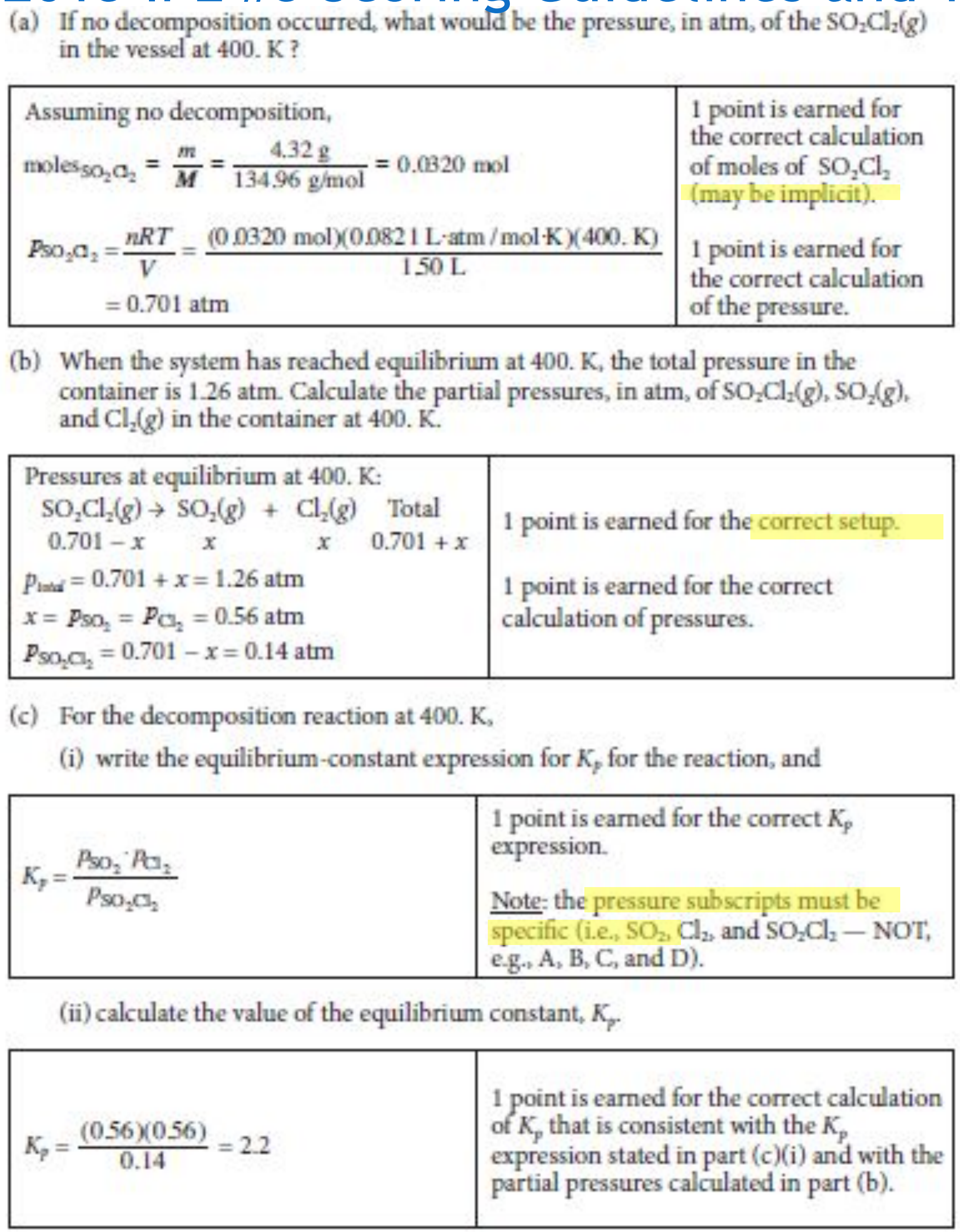
(c) For the decomposition reaction at 400. K,

- (i) write the equilibrium-constant expression for K_p for the reaction, and
- (ii) calculate the value of the equilibrium constant, K_p.

(d) The temperature of the equilibrium mixture is increased to 425 K. Will the value of K_p increase, decrease, or remain the same? Justify your prediction.

(e) In another experiment, the original partial pressures of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ are 1.0 atm each at 400. K. Predict whether the amount of $SO_2Cl_2(g)$ in the container will increase, decrease, or remain the same. Justify your prediction.

2013 IPE #3 Scoring Guidelines and Things to Notice



(a) If no decomposition occurred, what would be the pressure, in atm, of the $SO_2Cl_2(g)$ in the vessel at 400. K ?

Assuming no decomposition, $\text{moles}_{SO_2Cl_2} = \frac{m}{M} = \frac{4.32\text{ g}}{134.96\text{ g/mol}} = 0.0320\text{ mol}$	1 point is earned for the correct calculation of moles of SO_2Cl_2 (may be implicit).
$P_{SO_2Cl_2} = \frac{nRT}{V} = \frac{(0.0320\text{ mol})(0.0821\text{ L}\cdot\text{atm / mol}\cdot\text{K})(400.\text{ K})}{1.50\text{ L}}$ $= 0.701\text{ atm}$	1 point is earned for the correct calculation of the pressure.

(b) When the system has reached equilibrium at 400. K, the total pressure in the container is 1.26 atm. Calculate the partial pressures, in atm, of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ in the container at 400. K.

Pressures at equilibrium at 400. K: $SO_2Cl_2(g) \rightarrow SO_2(g) + Cl_2(g)$ Total $0.701 - x$ x x $0.701 + x$	1 point is earned for the correct setup.
$P_{total} = 0.701 + x = 1.26\text{ atm}$ $x = P_{SO_2} = P_{Cl_2} = 0.56\text{ atm}$ $P_{SO_2Cl_2} = 0.701 - x = 0.14\text{ atm}$	1 point is earned for the correct calculation of pressures.

(c) For the decomposition reaction at 400. K,

(i) write the equilibrium-constant expression for K_p for the reaction, and

$K_p = \frac{P_{SO_2} \cdot P_{Cl_2}}{P_{SO_2Cl_2}}$	1 point is earned for the correct K_p expression. Note: the pressure subscripts must be specific (i.e., SO_2, Cl_2, and SO_2Cl_2 — NOT, e.g., A, B, C, and D).

(ii) calculate the value of the equilibrium constant, K_p.

$K_p = \frac{(0.56)(0.56)}{0.14} = 2.2$	1 point is earned for the correct calculation of K_p that is consistent with the K_p expression stated in part (c)(i) and with the partial pressures calculated in part (b).

- Show work so that maximum points can be earned – do not have to stop and show value of moles, but work must demonstrate process to calculate it

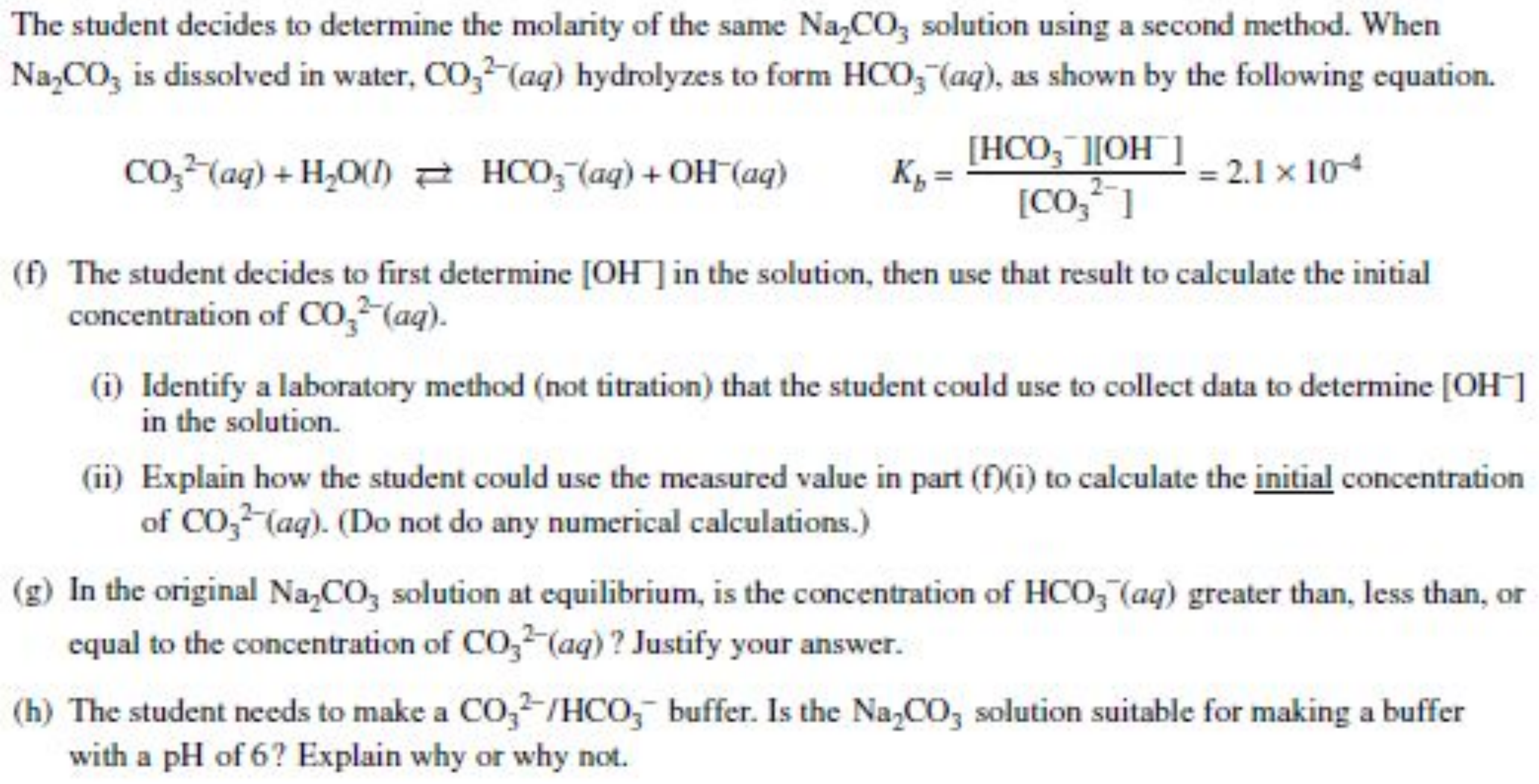
- Again, SHOW ALL WORK

- Be specific in responses, using proper names/formulas
- Must use P notation here, NOT [ ]

Unit 8: Acids and Bases

Write This…	…Not That!	Rationale
"The solution is neutral when $[H_3O^+] = [OH^-]$."	"The solution is neutral when pH=7."	True definition of neutral – neutral is only pH of 7 when $K_w = 1.0 \times 10^{-14}$ (at 298 K)
"The pH > 7 because the salt produced in the neutralization behaves as a base: $A^- + H_2O \quad HA + OH^-$"	"The pH > 7 because it's a battle between weak acid and strong base and strong base wins."	State the actual reason not the memory aid
HCl, HBr, HI, $HClO_4$, H_2SO_4, HNO_3 as strong acids	Any other acid as strong	These are the strong acids listed in the Course and Exam Description
$K_w = K_a \times K_b$ for a conjugate pair	$K_w = K_a \times K_b$ for an unrelated acid/base pair	This equation only holds true for conjugate acid-base pairs
A buffer system containing a weak acid and its conjugate base (or a weak base and its conjugate acid)	A buffer system that contains a strong acid or base; a buffer containing any acid/base with a common ion	A buffer results from the presence of a weak acid or base and its conjugate; a strong-strong system will neutralize without buffering
"This buffer has a higher buffering capacity because it contains a higher concentration of weak acid/base and its conjugate to react with added H^+ or OH^- ions."	"Higher volume of weak acid/base"	Buffering capacity is related to the presence of both the weak species and its conjugate.
Identifying a salt as making a good choice for a specified buffer because the pK_a is close to the desired pH for the buffer.	Identifying a salt as making a good choice for a specified buffer because the pK_b is close to the desired pH for the buffer.	An effective buffer is one in which is pKa of the weak acid is approximately equal to the target pH. (ref. 2019 #3h)
Answers that justify the relative concentrations of weak acid and conjugate base to the half-equivalence point on a titration curve	Answers that fail to recognize the importance of the half-equivalence point	Considering the position of a weak acid/strong base titration curve relative to the half-equivalence point can be used to deduce features of the titration because at this point pKa=pH and [WA]=[A-] (Ref 2022 1e)

Unit 8 Practice – 2019 Operational #3 (parts f-h)



The student decides to determine the molarity of the same Na_2CO_3 solution using a second method. When Na_2CO_3 is dissolved in water, $CO_3^{2-}(aq)$ hydrolyzes to form $HCO_3^-(aq)$, as shown by the following equation.

$$CO_3^{2-}(aq) + H_2O(l) \rightleftarrows HCO_3^-(aq) + OH^-(aq) \qquad K_b = \frac{[HCO_3^-][OH^-]}{[CO_3^{2-}]} = 2.1 \times 10^{-4}$$

(f) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.

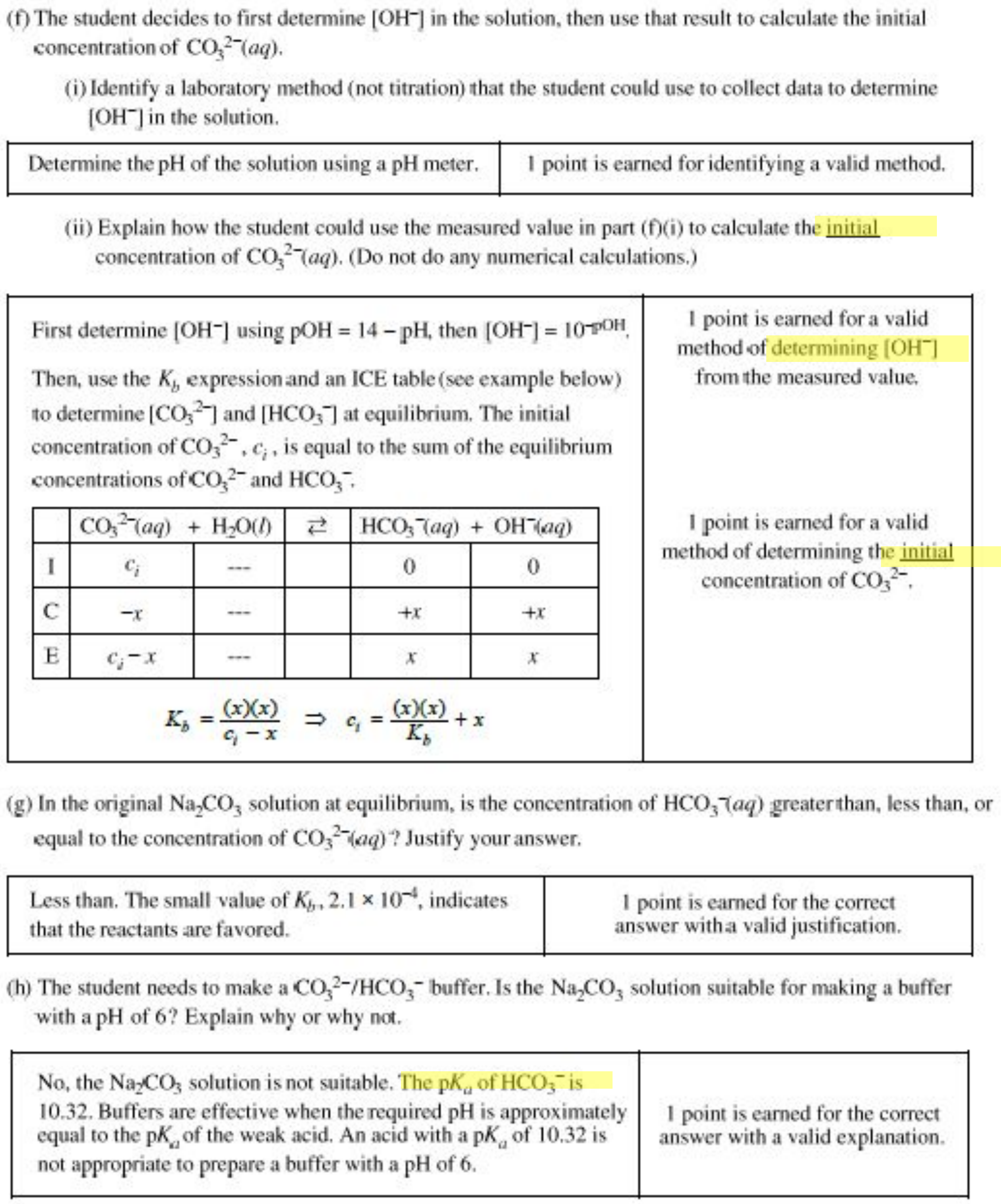
(i) Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution.

(ii) Explain how the student could use the measured value in part (f)(i) to calculate the initial concentration of $CO_3^{2-}(aq)$. (Do not do any numerical calculations.)

(g) In the original Na_2CO_3 solution at equilibrium, is the concentration of $HCO_3^-(aq)$ greater than, less than, or equal to the concentration of $CO_3^{2-}(aq)$? Justify your answer.

(h) The student needs to make a CO_3^{2-}/HCO_3^- buffer. Is the Na_2CO_3 solution suitable for making a buffer with a pH of 6 ? Explain why or why not.

2019 Operational #3 Scoring Guidelines and Things to Notice



(f) The student decides to first determine [OH^-] in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.

(i) Identify a laboratory method (not titration) that the student could use to collect data to determine [OH^-] in the solution.

Determine the pH of the solution using a pH meter.	1 point is earned for identifying a valid method.

(ii) Explain how the student could use the measured value in part (f)(i) to calculate the initial concentration of $CO_3^{2-}(aq)$. (Do not do any numerical calculations.)

First determine [OH^-] using pOH = 14 − pH, then [OH^-] = 10^{-pOH}.

Then, use the K_b expression and an ICE table (see example below) to determine [CO_3^{2-}] and [HCO_3^-] at equilibrium. The initial concentration of CO_3^{2-}, c_i, is equal to the sum of the equilibrium concentrations of CO_3^{2-} and HCO_3^-.

	$CO_3^{2-}(aq)$	+ $H_2O(l)$	⇄	$HCO_3^-(aq)$	+ $OH^-(aq)$
I	c_i	---		0	0
C	$-x$	---		$+x$	$+x$
E	$c_i - x$	---		x	x

$$K_b = \frac{(x)(x)}{c_i - x} \Rightarrow c_i = \frac{(x)(x)}{K_b} + x$$

1 point is earned for a valid method of determining [OH^-] from the measured value.

1 point is earned for a valid method of determining the initial concentration of CO_3^{2-}.

(g) In the original Na_2CO_3 solution at equilibrium, is the concentration of $HCO_3^-(aq)$ greater than, less than, or equal to the concentration of $CO_3^{2-}(aq)$? Justify your answer.

Less than. The small value of K_b, 2.1×10^{-4}, indicates that the reactants are favored.	1 point is earned for the correct answer with a valid justification.

(h) The student needs to make a CO_3^{2-}/HCO_3^- buffer. Is the Na_2CO_3 solution suitable for making a buffer with a pH of 6? Explain why or why not.

No, the Na_2CO_3 solution is not suitable. The pK_a of HCO_3^- is 10.32. Buffers are effective when the required pH is approximately equal to the pK_a of the weak acid. An acid with a pK_a of 10.32 is not appropriate to prepare a buffer with a pH of 6.	1 point is earned for the correct answer with a valid explanation.

- Show work so that maximum points can be earned – they must be able to see how you calculated [OH-]

- Read the prompt carefully – this required initial, where often we are working with equilibrium values

- A buffer is a good choice when the pK_a is close to the desired pH – be sure to discuss the pK_a not the pK_b

Unit 9: Applications of Thermodynamics

Write This…	…Not That!	Rationale
Reference number of molecules and phases when justifying a change in ΔS based on a reaction	Making vague references to “similar structures” or no justification	An increase in ΔS is due to an increase in number of gaseous products (ref. 2017 #2c)
Multiplying $\Delta S°$ values by stoichiometric factors when calculating $\Delta S°_{rxn}$	Ignoring stoichiometry when calculating $\Delta S°_{rxn}$	Correct application of the equation $\Delta S°_{rxn} = \sum \Delta S°_{products} - \sum \Delta S°_{reactants}$ (Ref. 2021 #2e, 2022 #2b)
Using consistent units when applying $\Delta G = \Delta H - T\Delta S$	Not having all 3 thermodynamic factors in the same unit (either kJ or J)	Units must be consistent when used in equations (Ref. 2022 #2cii)
Justify thermodynamic favorability in terms of both enthalpy and entropy	A thermodynamic favorability discussion referencing only enthalpy or entropy	Thermodynamic favorability depends on both ΔH and ΔS
Arrangement/Dispersions of matter or energy along with particle-level reasoning for explaining the sign of ΔS	Disorder, chaos	Disorder is the effect, not the cause, of an increase in entropy (ref. 2019 #1g)
ΔG determines thermodynamic favorability	Referencing ΔH or ΔS alone as determining thermodynamic favorability	All the thermodynamic properties contribute to favorability – hence using $\Delta G = \Delta H - T\Delta S$ which takes all into account (ref. 2019 #1h)
Use of correct value of R with thermodynamic data (that corresponds to energy units)	R value that does not correspond to the units needed in the problem	Units of the R value must match those used in the problem, and correct units must be applied at the end, or the answer is incorrect (ref. 2018 #2b)

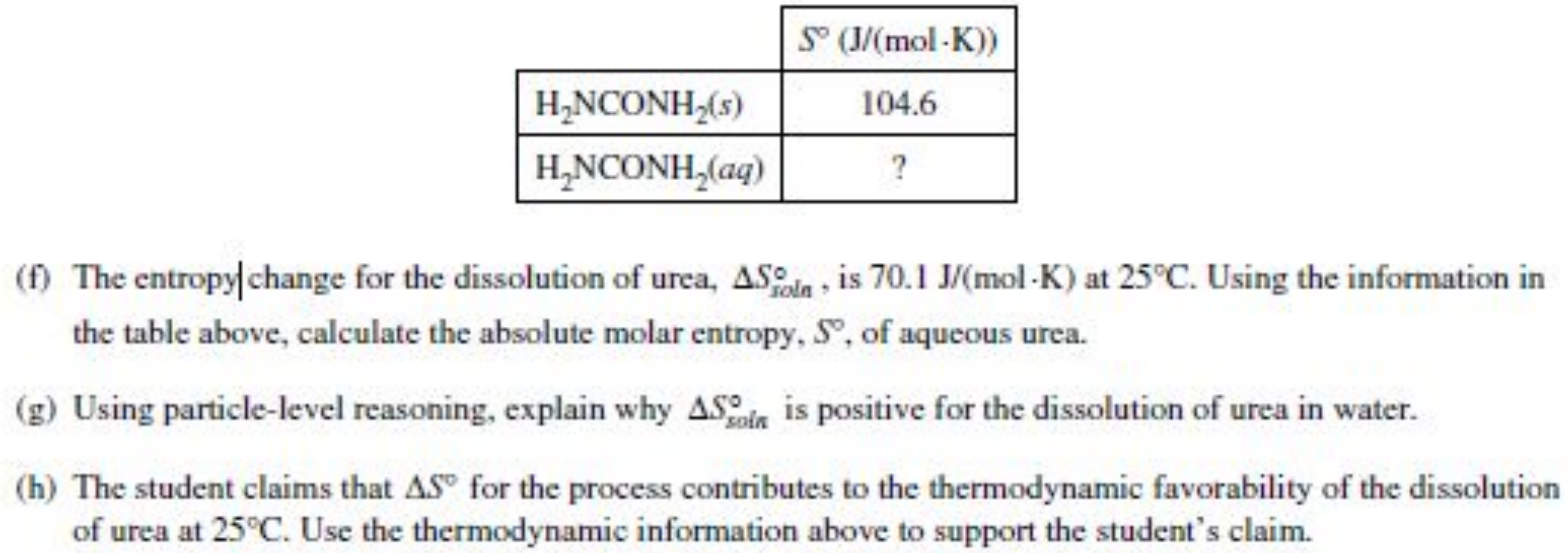
Unit 9: Applications of Thermodynamics (cont.)

Write This…	…Not That!	Rationale
“Ions flow through the salt bridge to maintain a charge balance in each half-cell.”	“Electrons flow through the salt bridge to equilibrate charge.”	Electrons do not flow through the salt bridge; ions flow through the salt bridge, electrons flow through the wire (ref. 2018 #6a)
Loss of mass of electrode is due to atoms of electrode going into solution as ions	Loss of mass of electrode is due to loss of electrons	Electrons have extremely small (negligible in this case) mass (ref. 2014 #3)
Discussion of Q vs. K for changes in cell potential after a change, or qualitative discussion of Nernst Equation	Discussion of Le Châtelier’s principle	An galvanic cell does not attain equilibrium while working – when it does, it stops producing current (is “dead”) (ref. 2014 #3)
An equation that is balanced with respect to both number of atoms and charge	An equation that is unbalanced in atoms, charge or both; an equation that shows electrons	Recognize that equations need to be balanced with respect to both atoms and charge – this means that half-reactions may need to multiplied by a coefficient to balance charge for the overall reaction, even if atoms are already balanced, and then the electrons on both sides cancel out and are not written (ref. 2018 #3d)
E° values that are positive for galvanic cells and negative for electrolytic cells	E° values that have the wrong sign	Galvanic cells are thermodynamically favorable as proceed as designed with a + E°, electrolytic cells are thermodynamically unfavorable with a - E° and require an external driving force (Ref. 2021#5b)
E° value not multiplied by stoichiometric factors	E° value that has been multiplied by a stoichiometric value	E° is intensive and therefore does not change if the half-cell is multiplied by a stoichiometric factor to balance charge (ref. 2018 #6b, 2022 3e)
Standard cell potential when discussing a REDOX reaction	Standard reduction potential when discussing a REDOX reaction	A redox reaction contains both oxidation and reduction; therefore the E° for the reaction is the sum of the standard reduction potentials of both the

Unit 9: Applications of Thermodynamics (cont.)

Write This…	…Not That!	Rationale
When writing $E°_{cell}$ for favorable redox reactions, one rxn must be reversed so that $E°_{cell}$ is positive	An $E°_{cell}$ that is negative for redox reactions that proceed in the forward direction	There has to be thermodynamic favorability, which depends on the $E°_{cell}$, in order for the rxn to work (ref. 2019 #2b)
Using the cell potential for E° in $\Delta G = -nFE°$ calculations	Using a half-cell potential for E° in $\Delta G = -nFE°$ calculations	This equation uses the full cell potential, not for a half-reaction (ref. 2018 #6b)
Performing calculations with mass and current (using Faraday's constant) that account for the number of moles of electrons transferred	Performing calculations with mass and current (using Faraday's constant) without considering the number of moles of electrons transferred	Stoichiometry between the moles of the target species and the moles of electrons transferred in the reaction must be included (Ref. 2021 #5c)

Unit 9 Practice – 2019 Operational #1 (parts f-h)



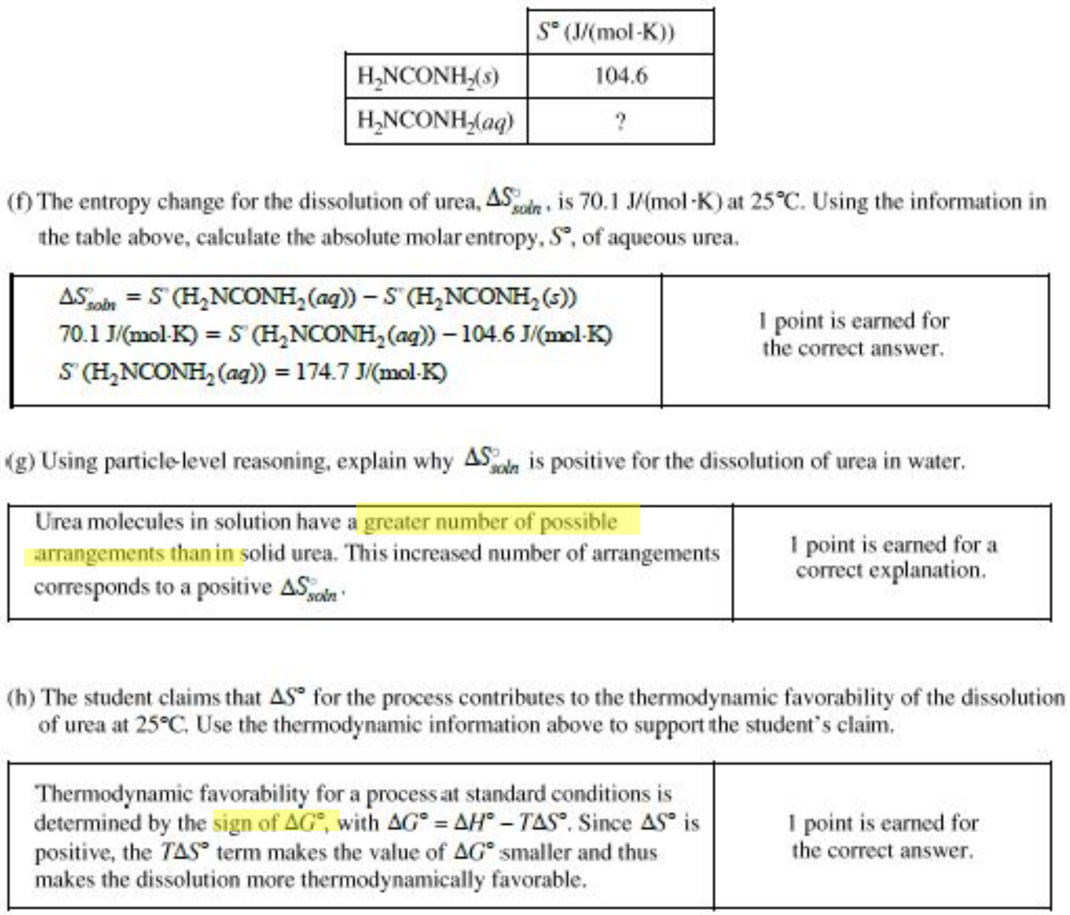
	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

(f) The entropy change for the dissolution of urea, ΔS°_{soln}, is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, $S°$, of aqueous urea.

(g) Using particle-level reasoning, explain why ΔS°_{soln} is positive for the dissolution of urea in water.

(h) The student claims that $\Delta S°$ for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

2019 Operational #1 Scoring Guidelines and Things to Notice



	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

(f) The entropy change for the dissolution of urea, $\Delta S°_{soln}$, is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, $S°$, of aqueous urea.

$\Delta S°_{soln} = S°(H_2NCONH_2(aq)) - S°(H_2NCONH_2(s))$ $70.1\ J/(mol{\cdot}K) = S°(H_2NCONH_2(aq)) - 104.6\ J/(mol{\cdot}K)$ $S°(H_2NCONH_2(aq)) = 174.7\ J/(mol{\cdot}K)$	1 point is earned for the correct answer.

(g) Using particle-level reasoning, explain why $\Delta S°_{soln}$ is positive for the dissolution of urea in water.

Urea molecules in solution have a greater number of possible arrangements than in solid urea. This increased number of arrangements corresponds to a positive $\Delta S°_{soln}$.	1 point is earned for a correct explanation.

(h) The student claims that $\Delta S°$ for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

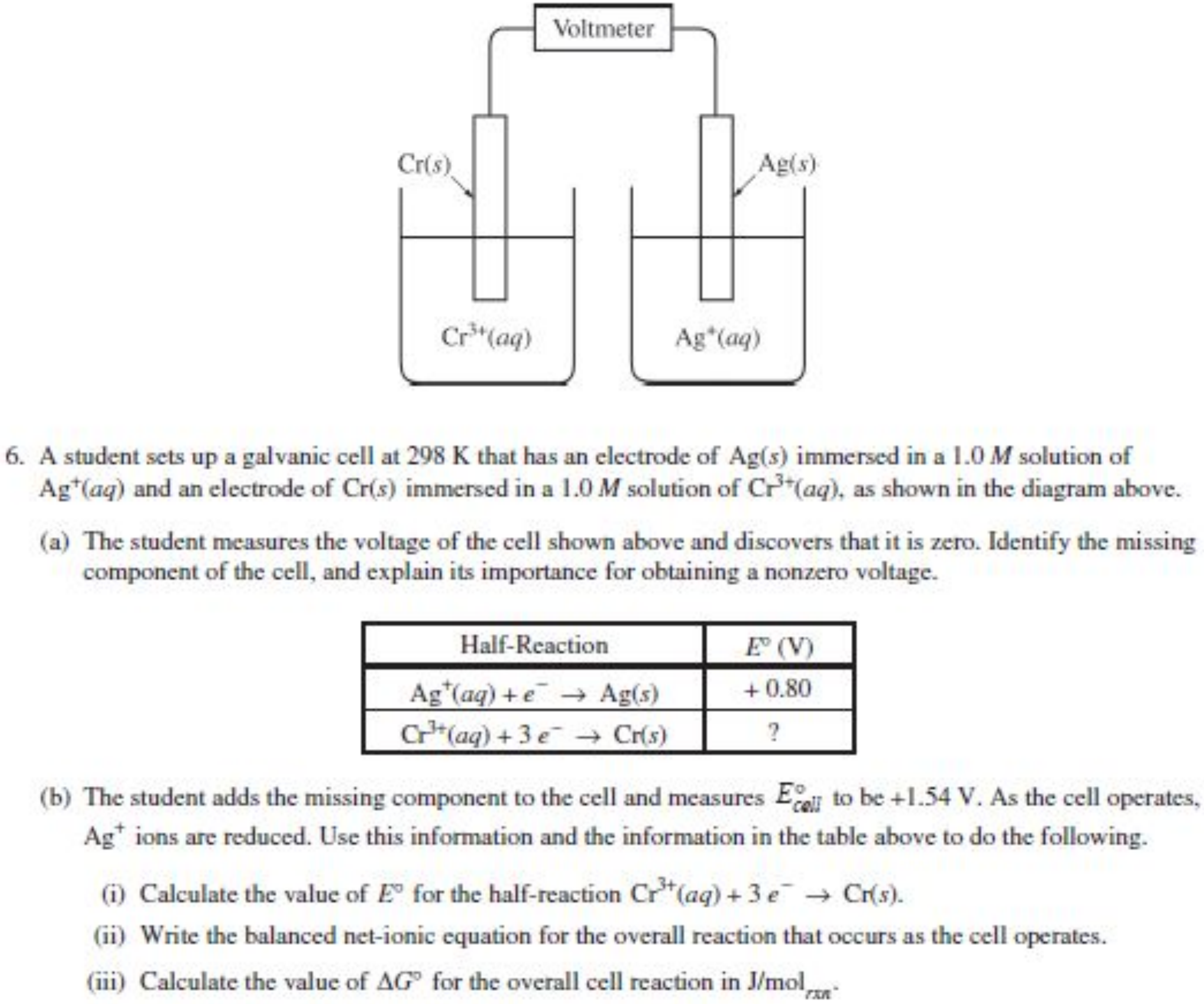
Thermodynamic favorability for a process at standard conditions is determined by the sign of $\Delta G°$, with $\Delta G° = \Delta H° - T\Delta S°$. Since $\Delta S°$ is positive, the $T\Delta S°$ term makes the value of $\Delta G°$ smaller and thus makes the dissolution more thermodynamically favorable.	1 point is earned for the correct answer.

- Make sure you do products-reactants
- SHOW ALL WORK

- Arrangement/Dispersions of matter or energy along with particle-level reasoning for explaining the sign of ΔS, not just staying "disorder increases" or "chaos increases"

- ΔG determines thermodynamic favorability
- Do not reference ΔH or ΔS alone as determining thermodynamic favorability

Unit 9 Practice – 2018 Operational #6



6. A student sets up a galvanic cell at 298 K that has an electrode of Ag(*s*) immersed in a 1.0 *M* solution of $Ag^{+}(aq)$ and an electrode of Cr(*s*) immersed in a 1.0 *M* solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$	?

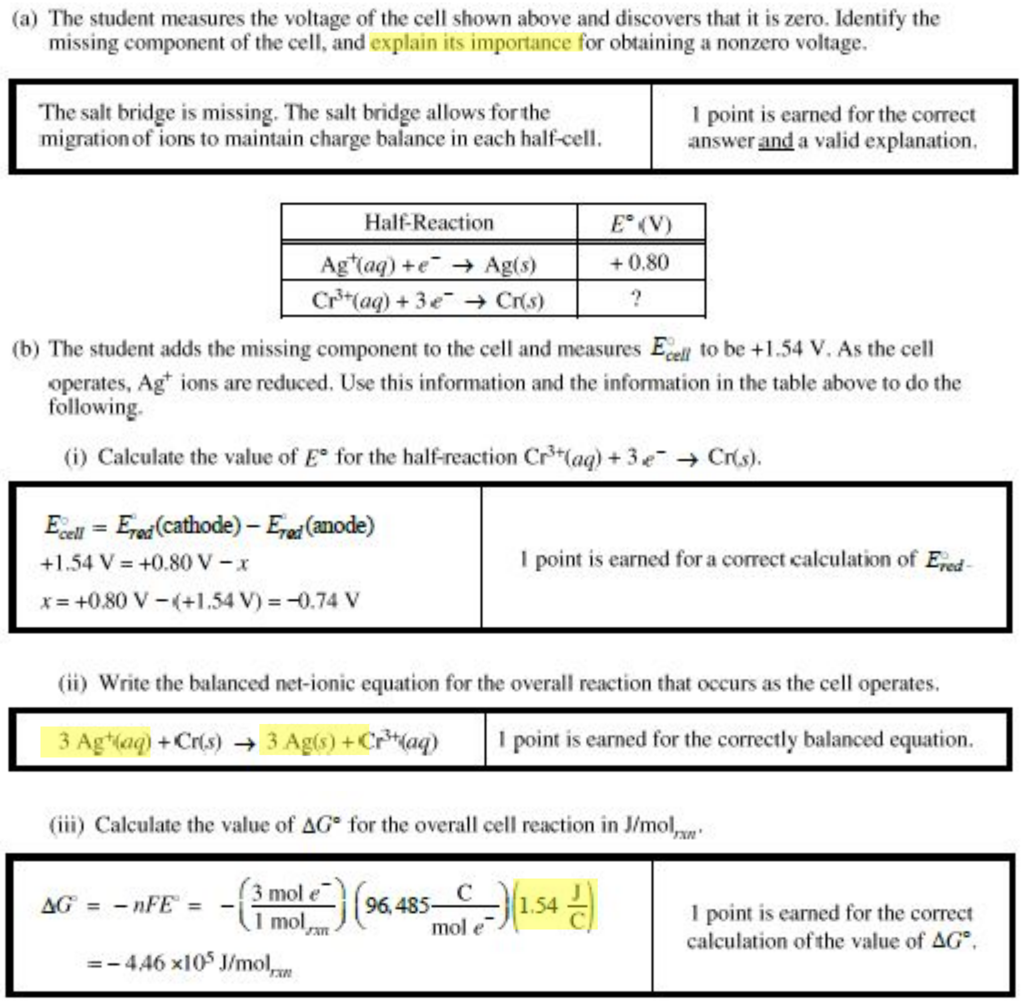
(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol$_{rxn}$.

2018 Operational #6 Scoring Guidelines and Things to Notice



(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

The salt bridge is missing. The salt bridge allows for the migration of ions to maintain charge balance in each half-cell.	1 point is earned for the correct answer and a valid explanation.

- The point is not earned unless the missing component AND the importance are both included

Half-Reaction	$E°$ (V)
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+0.80
$Cr^{3+}(aq) + 3e^- \rightarrow Cr(s)$	?

(b) The student adds the missing component to the cell and measures E°_{cell} to be +1.54 V. As the cell operates, Ag^+ ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3e^- \rightarrow Cr(s)$.

$E^\circ_{cell} = E^\circ_{red}(\text{cathode}) - E^\circ_{red}(\text{anode})$ $+1.54\text{ V} = +0.80\text{ V} - x$ $x = +0.80\text{ V} - (+1.54\text{ V}) = -0.74\text{ V}$	1 point is earned for a correct calculation of E°_{red}.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

$3\,Ag^+(aq) + Cr(s) \rightarrow 3\,Ag(s) + Cr^{3+}(aq)$	1 point is earned for the correctly balanced equation.

- REDOX equations must be balanced for both number of atoms AND number of electrons

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol_{rxn}.

$\Delta G^\circ = -nFE^\circ = -\left(\frac{3\text{ mol }e^-}{1\text{ mol}_{rxn}}\right)\left(96{,}485\frac{\text{C}}{\text{mol }e^-}\right)\left(1.54\frac{\text{J}}{\text{C}}\right)$ $= -4.46 \times 10^5\text{ J/mol}_{rxn}$	1 point is earned for the correct calculation of the value of $\Delta G°$.

- The n is from the number of electrons transferred in the balanced equation
- Use the cell potential for the entire cell (1.54), not for one of the half-reactions