2021

AP® CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

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Free Response Question 2

☑ Scoring Guideline

☑ Student Samples

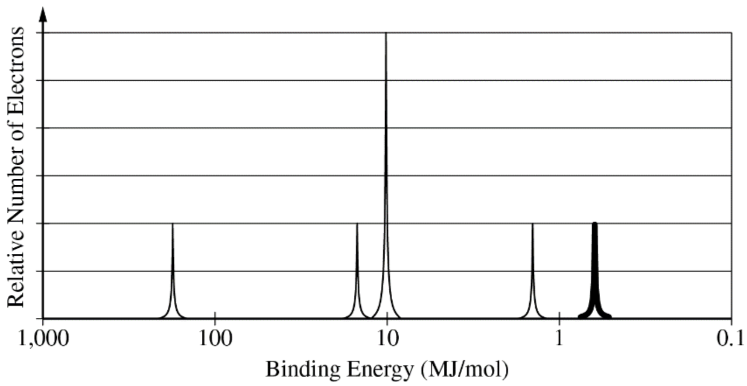
☑ Scoring Commentary

Question 2: Long Answer — 10 points

(a)	**(i)** For the correct answer: *14 protons and 14 neutrons*	**1 point**
	(ii) For the correct answer: Accept one of the following: • $1s^2\,2s^2\,2p^6\,3s^2\,3p^2$ • $[Ne]\,3s^2\,3p^2$	**1 point**
	Total for part (a)	**2 points**
(b)	For a correct explanation: *SiH_4 is composed of molecules, for which the only intermolecular forces are London dispersion forces. SiO_2 is a network covalent compound with covalent bonds between silicon and oxygen atoms. London dispersion forces are much weaker than covalent bonds, so SiH_4 boils at a much lower temperature than SiO_2.*	**1 point**
(c)	For the correct balanced equation (state symbols not required): $SiH_4(g) \rightarrow Si(s) + 2\ H_2(g)$	**1 point**
(d)	For a correct explanation: *The $H_2(g)$ molecules are more highly dispersed than the Si(s) atoms and, therefore, have a higher absolute molar entropy. Silicon is a solid; therefore, its atoms are in fixed positions, are less dispersed, and have a lower absolute molar entropy.*	**1 point**
(e)	For the correct calculated value: $\Delta S^\circ_{rxn} = (18 + 2(131)) - 205 = +75\ \text{J/(mol}_{rxn} \cdot \text{K)}$	**1 point**
(f)	For a correct explanation: *High temperature is required for the reactant particles to have sufficient thermal energy to overcome the activation energy of the reaction.*	**1 point**

(g)	For the correct peak height and location:	**1 point**

The peak should be drawn to the right of the other peaks, and it should reach the second line above the horizontal axis.



(h)	For a correct explanation:	**1 point**

The valence electrons of a Ge atom occupy a higher shell (n=4) than those of a Si atom (n=3), so the average distance between the nucleus and the valence electrons is greater in Ge than in Si. This greater separation results in weaker Coulombic attractions between the Ge nucleus and its valence electrons, making them less tightly bound and, therefore, easier to remove compared to those in Si.

(i)	For the correct calculated value:	**1 point**

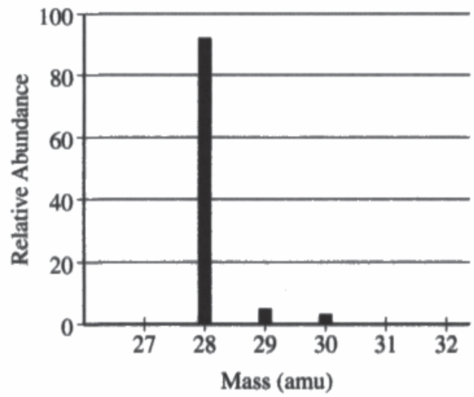
$$E = h\nu = h\left(\frac{c}{\lambda}\right) = 6.626\times10^{-34}\ \text{J}\cdot\text{s}\left(\frac{2.998\times10^{8}\ \text{m s}^{-1}}{4.00\times10^{-7}\ \text{m}}\right) = 4.97\times10^{-19}\ \text{J}$$

Total for question 2 10 points

Begin your response to **QUESTION 2** on this page.

2. Answer the following questions about the element Si and some of its compounds.

(a) The mass spectrum of a pure sample of Si is shown below.



(i) How many protons and how many neutrons are in the nucleus of an atom of the most abundant isotope of Si ? mass = 28

protons = 14   neutrons = 14

(ii) Write the ground-state electron configuration of Si.

$1s^2 2s^2 2p^6 3s^2 3p^2$

Two compounds that contain Si are SiO_2 and SiH_4.

(b) At 161 K, SiH_4 boils but SiO_2 remains as a solid. Using principles of interparticle forces, explain the difference in boiling points.

SiH_4 only intermolecular force only is ~~Slude~~ London Dispersion Forces (LDFs). SiO_2 only intermolecular force is LDFs as well. However, SiO_2 is a network covalent solid, which means its covalent bonds are extremely strong and hard to break. Since SiO_2 is a network covalent solid, it has a much higher boiling point.

Continue your response to **QUESTION 2** on this page.

At high temperatures, SiH_4 decomposes to form solid silicon and hydrogen gas.

(c) Write a balanced equation for the reaction.

$SiH_4 \longrightarrow Si_{(s)} + 2H_{2(g)}$

A table of absolute entropies of some substances is given below.

Substance	$S°$ (J/(mol · K))
$H_2(g)$	131
$Si(s)$	18
$SiH_4(g)$	205

(d) Explain why the absolute molar entropy of $Si(s)$ is less than that of $H_2(g)$.

Silicon is a solid, which means that it cannot move freely like a gas can. Entropy is the measure of randomness of a compound. A gas can move freely so it has a higher entropy.

(e) Calculate the value, in J/(mol· K), of $\Delta S°$ for the reaction.

$(18+2(131)) - 205 = 75 \frac{J}{mol \cdot K}$

(f) The reaction is thermodynamically favorable at all temperatures. Explain why the reaction occurs only at high temperatures.

Since the reaction is a decomposition reaction bonds must be broken. This requires energy to be added to the system. At high temperatures there is enough energy to break these bonds, and more particles can get over the activation energy barrier

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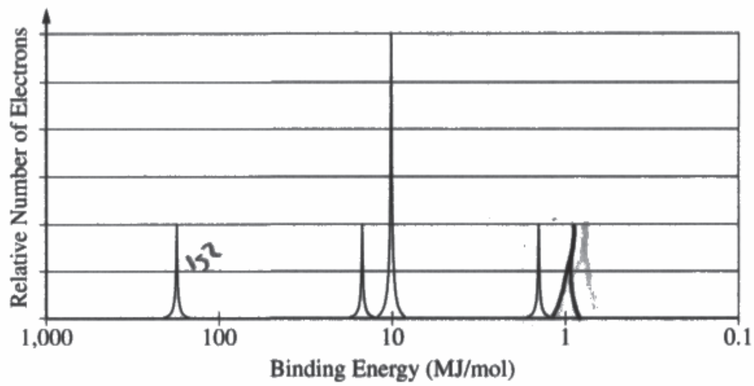
Continue your response to **QUESTION 2** on this page.

(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the 3*p* sublevel.



(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

Si has a higher effective nuclear charge then Ge does. Si also has electrons in a lower quantam level then Ge does. Since the electrons are farther away from the nucleus in Ge their hold to the nucleus is weak, so the 1st ionization energy is lower.

(i) A single photon with a wavelength of 4.00×10^{-7} m is absorbed by the Si sample. Calculate the energy of the photon in joules.

$2.998 \times 10^{8} = 4.00 \times 10^{-7}(v)$

$v = 7.495 \times 10^{14}$

$E = 6.626 \times 10^{-34}(7.495 \times 10^{14})$

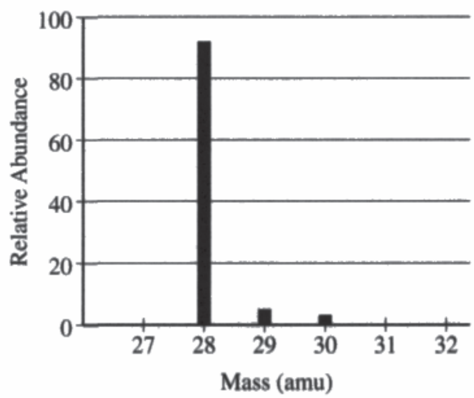
$E = 4.97 \times 10^{-19}$ J

GO ON TO THE NEXT PAGE.

Begin your response to QUESTION 2 on this page.

2. Answer the following questions about the element Si and some of its compounds.

(a) The mass spectrum of a pure sample of Si is shown below.



(i) How many protons and how many neutrons are in the nucleus of an atom of the most abundant isotope of Si ?

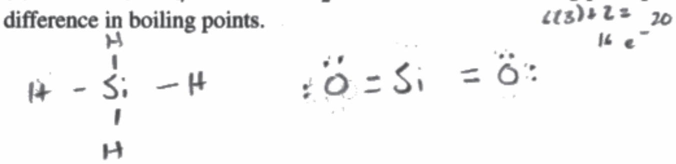
14 protons & 14 neutrons

(ii) Write the ground-state electron configuration of Si.

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$

Two compounds that contain Si are SiO_2 and SiH_4.

(b) At 161 K, SiH_4 boils but SiO_2 remains as a solid. Using principles of interparticle forces, explain the difference in boiling points.



Both SiH_4, + SiO_2 are nonpolar compounds with london dispersion forces. Because SiO_2 has more electrons, it is more polarizable which makes its intermolecular forces greater than SiH_4. This is why SiH_4 has a lower boiling point.

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Continue your response to **QUESTION 2** on this page.

At high temperatures, SiH_4 decomposes to form solid silicon and hydrogen gas.

(c) Write a balanced equation for the reaction.

$SiH_4(g) \rightarrow Si(s) + 2H_2(g)$

A table of absolute entropies of some substances is given below.

Substance	S° (J/(mol · K))
$H_2(g)$	131
$Si(s)$	18
$SiH_4(g)$	205

(d) Explain why the absolute molar entropy of $Si(s)$ is less than that of $H_2(g)$.

It is less than that of $H_2(g)$ because a gas moves freely throughot its container, making the disorder increase.

(e) Calculate the value, in J/(mol· K), of ΔS° for the reaction.

$\Delta S = \Sigma S^\circ_{products} - \Sigma S^\circ_{reactants}$

$\Delta S = (2(131) + 18) - (205)$ $\Delta S = 75$ J/mol K

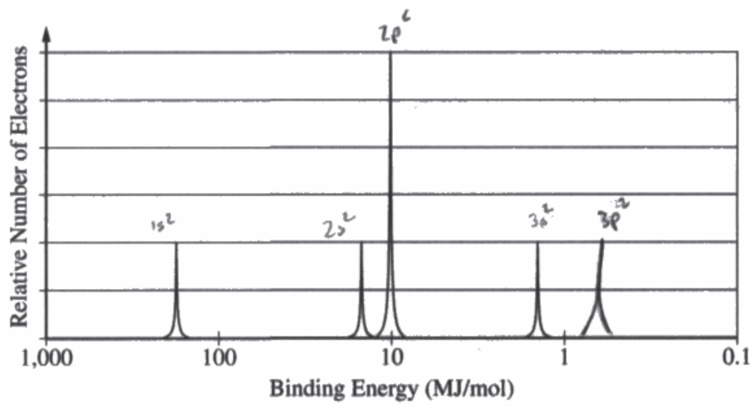
(f) The reaction is thermodynamically favorable at all temperatures. Explain why the reaction occurs only at high temperatures.

The reaction only occurs at high temperatures because ΔH must be positive. The higher the temp the more negative the value of $-T\Delta S$ will be and the more will be subtracted from ΔH to make ΔG a negative value.

$\Delta G = \Delta H - T\Delta S$

Continue your response to QUESTION 2 on this page.

(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the $3p$ sublevel.



(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

The first IE is lower in Ge because Ge has electrons in the 4p energy level and Si has electrons in the 3p level. The 4p level is farther from the nucleus, making the attraction between the protons & electrons weaker, so it requires less energy to remove an e⁻.

(i) A single photon with a wavelength of 4.00×10^{-7} m is absorbed by the Si sample. Calculate the energy of the photon in joules.

$c = \lambda v$

$2.998 \times 10^{8} = 4.00 \times 10^{-7} \, v$

$v = 7.495 \times 10^{14}$

$E = hv$

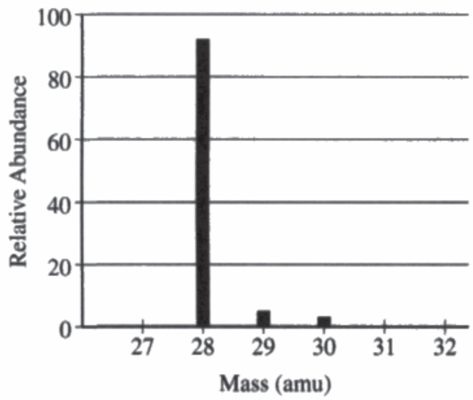
$E = (6.626 \times 10^{-34})(7.495 \times 10^{14})$

$E = 4.97 \times 10^{-19}$ J

Begin your response to **QUESTION 2** on this page.

2. Answer the following questions about the element Si and some of its compounds.

(a) The mass spectrum of a pure sample of Si is shown below.



(i) How many protons and how many neutrons are in the nucleus of an atom of the most abundant isotope of Si ?

28-14

There are 14 protons and 14 neutrons.

(ii) Write the ground-state electron configuration of Si.

$1s^2 2s^2 2p^6 3s^2 3p^2$

Two compounds that contain Si are SiO_2 and SiH_4.

(b) At 161 K, SiH_4 boils but SiO_2 remains as a solid. Using principles of interparticle forces, explain the difference in boiling points.

SiH_4 boils before SiO_2 because SiH_4 contains four Hydrogens which speed up the reaction whereas SiO_2 has no hydrogens.

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Continue your response to QUESTION 2 on this page.

At high temperatures, SiH_4 decomposes to form solid silicon and hydrogen gas.

(c) Write a balanced equation for the reaction.

$$SiH_{4(aq)} \rightleftharpoons Si_{(s)} + H_4^{+}{}_{(g)}$$

A table of absolute entropies of some substances is given below.

Substance	$S°$ (J/(mol · K))
$H_2(g)$	131
$Si(s)$	18
$SiH_4(g)$	205

(d) Explain why the absolute molar entropy of $Si(s)$ is less than that of $H_2(g)$.

$Si_{(s)}$ has a lower molar entropy than $H_{2(g)}$ because it does not have hydrogen bonding and is not as thermodynamically favored.

(e) Calculate the value, in J/(mol· K), of $\Delta S°$ for the reaction.

$$\Delta S° = (205\ J/mol \cdot K) - (149\ J/mol \cdot K)$$

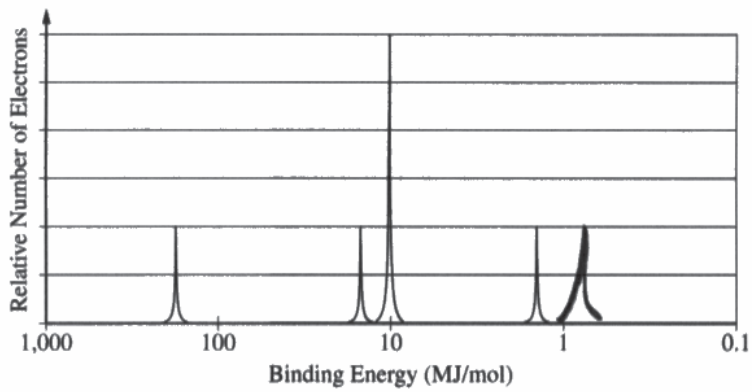
$$\Delta S° = 56\ J/(mol \cdot K)$$

(f) The reaction is thermodynamically favorable at all temperatures. Explain why the reaction occurs only at high temperatures.

$\Delta H°$ and $\Delta S°$ are $<$ $>$. which shows that the reaction is thermodynamically favorable for all temperature, but in high temperatures $\Delta H°$ and $\Delta S°$, respectively, are $>$ $>$, so the reaction only occurs in high temperatures because the signs are both $>$ for $\Delta S°$

Continue your response to **QUESTION 2** on this page.

(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the $3p$ sublevel.



(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

Ge has more valence electrons and a lower electronegarivity plus its below Si on the periodic table resulting in a lower first ionization energy than that of Si.

(i) A single photon with a wavelength of 4.00×10^{-7} m is absorbed by the Si sample. Calculate the energy of the photon in joules.

$E = h\nu$

$E = (6.626 \times 10^{-34}\ \text{Js})(4.00 \times 10^{-7}\ \text{m})$

$E = 2.6504 \times 10^{-40}$

Question 2

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 2 deals with the atomic structure of silicon and the properties of silicon-containing compounds. In part (a)(i), the student is asked to interpret a mass spectrum to determine the number of subatomic particles in the most abundant isotope of Si (SPQ-1.B, 5.D). Part (a)(ii) asks for the ground-state electron configuration of Si (SAP-1.A, 3.B). In part (b), the student must use principles of interparticle forces to explain the relative boiling points of SiH_4 vs. SiO_2 (SAP-5.B, 6.E).

Part (c) asks for the balanced chemical equation that describes the decomposition of SiH_4 into elemental silicon and hydrogen gas (TRA-1.B, 5.E). These two products have different absolute molar entropies, as shown in a data table, and the student is asked to explain why $S°$ of solid Si is less than that of H_2 gas (ENE-4.A, 6.E). The absolute entropies are used in part (e) to calculate the standard entropy change of the reaction (ENE-4.B, 5.F). Part (f) then asks for an explanation for why the reaction occurs only at high temperatures (ENE-4.D, 4.A), despite being thermodynamically favorable at all temperatures.

Part (g) shows an incomplete photoelectron spectrum of silicon, which must be completed by drawing the missing peak corresponding to the electrons in the *3p* subshell (SAP-1.B, 3.A). Part (h) asks the student to compare the first ionization energies of Si and Ge using principles of atomic structure (SAP-2.A, 6.C). Finally, part (i) involves a calculation of the energy of a single photon of a given wavelength (SAP-8.B, 5.F).

Sample: 2A
Score: 10

Part (a)(i) earned 1 point. The response gives the correct numbers of protons and neutrons in the most abundant isotope of Si. Part (a)(ii) earned 1 point. The response gives the correct electron configuration of Si. Part (b) earned 1 point. The response correctly identifies the interparticle forces as London dispersion forces in SiH_4 and as covalent bonds in the network covalent solid SiO_2. The comment about LDFs in SiO_2 was ignored since the comparison is between the strength of covalent bonds in a network covalent solid and LDFs in a molecular solid. Part (c) earned 1 point. The response shows a correct and balanced equation for the decomposition of SiH_4 to form Si and H_2. Part (d) earned 1 point. The response explains the difference in molar entropy correctly by indicating that the particles in a solid cannot move freely while those in a gas can. Part (e) earned 1 point. The response shows a correct calculation of the entropy change for the reaction. Part (f) earned 1 point. The response states correctly that at high temperature the particles have enough energy to overcome the activation energy barrier. Part (g) earned 1 point. The response correctly shows a peak on the spectrum at the correct location and height. Part (h) earned 1 point. The response correctly includes an additional quantum level, increased electron-nuclear distance, and weaker electron-nuclear attraction to explain the lower ionization energy of Ge. The comment about effective nuclear charge was ignored since the shell structure of the atom is correctly described. Part (i) earned 1 point. The response correctly calculates the energy of the photon.

Sample: 2B
Score: 7

Part (a)(i) earned 1 point. The response gives the correct numbers of protons and neutrons in the most abundant isotope of Si. Part (a)(ii) earned 1 point. The response gives the correct electron configuration of Si. No point was earned for part (b). The response does not state that SiO_2 is a network covalent solid in which the interparticle forces are covalent bonds. Part (c) earned 1 point. The response shows a correct and balanced equation for the decomposition of SiH_4 to form Si and H_2. No point was earned for part (d). The response states that the particles in a gas move freely but does not compare that to the particles in Si(s), so it did not earn the point. Part (e) earned 1 point. The response shows a correct calculation of the entropy change for the reaction. No point was earned for part (f). The response incorrectly uses the temperature dependence of ΔG and the relative sizes of ΔH and $- T\Delta S$ to explain that the reaction only occurs at high temperatures. However, the stem

Question 2 (continued)

states that the reaction is thermodynamically favorable at all temperatures. Part (g) earned 1 point. The response correctly shows a peak on the spectrum at the correct location and height. Part (h) earned 1 point. The response correctly includes an additional energy level, increased electron-nuclear distance, and weaker electron-nuclear attraction to explain the lower ionization energy of Ge. Part (i) earned 1 point. The response correctly calculates the energy of the photon.

Sample: 2C
Score: 3

Part (a)(i) earned 1 point. The response gives the correct numbers of protons and neutrons in the most abundant isotope of Si. Part (a)(ii) earned 1 point. The response gives the correct electron configuration of Si. No point was earned for part (b). The response does not identify the interparticle forces in either SiH_4 or SiO_2. No point was earned for part (c). The response shows an incorrect equation for the decomposition of SiH_4. No point was earned for part (d). The response does not describe entropy of particles in the solid and gas phases, so it did not earn the point. No point was earned for part (e). The response shows an incorrect calculation of the entropy change in the reaction. No point was earned for part (f). The response incorrectly attempts to use the signs of $\Delta H°$ and $\Delta S°$ to explain that the reaction only occurs at high temperatures. However, the stem states that the reaction is thermodynamically favorable at all temperatures. Part (g) earned 1 point. The response correctly shows a peak on the spectrum at the correct location and height. No point was earned for part (h). The response mentions the periodic trend of electronegativity but has no atomic structure explanation for the lower ionization energy of Ge, so it did not earn the point. No point was earned for part (i). The response incorrectly calculates the energy of the photon.