Past-paper walk-through

Properties of Photons ▪ 3.12

eXercise

Questions in this set

- 2021 Q2
- 2019 Q5

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 2

2021 ▪ Q2

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

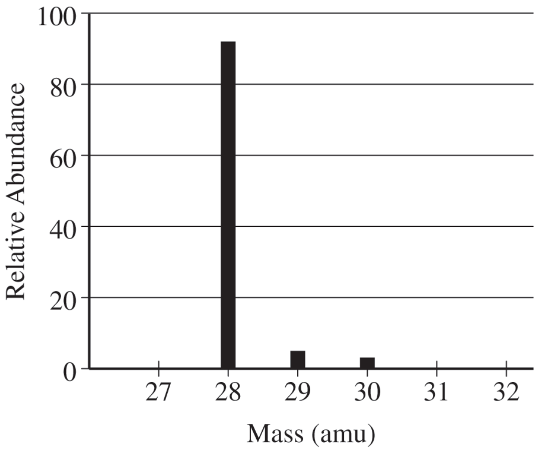
(a)(i) The mass spectrum of a pure sample of Si is shown below.

[Bar graph: Relative Abundance (y-axis, 0 to 100) vs. Mass (amu) (x-axis, 27 to 32). A tall bar of relative abundance ~92 at mass 28; a very small bar at mass 29 (~3); a very small bar at mass 30 (~4); negligible/no bars at 27, 31, 32.]

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

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

Question 2



Question 2

2021 ▪ Q2

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

(b) Two compounds that contain Si are SiO_2 and SiH_4.

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

Question 2

2021 ▪ Q2

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

(c) At high temperatures, SiH_4 decomposes to form solid silicon and hydrogen gas. Write a balanced equation for the reaction.

Question 2

2021 ▪ Q2

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

(d) 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

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

Question 2

2021 ▪ Q2

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

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

Question 2

2021 ▪ Q2

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

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

Question 2

2021 ▪ Q2

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

(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. [Photoelectron spectrum: Relative Number of Electrons (y-axis) vs. Binding Energy (MJ/mol) (x-axis, logarithmic scale decreasing left to right: 1,000, 100, 10, 1, 0.1). Peaks shown (from left to right, i.e. highest to lowest binding energy): a small peak near ~180 (between 1,000 and 100), a small peak near ~20 (between 100 and 10), a tall peak near ~10, and a small peak near ~1.5 (between 1 and 0.1). No peak is shown corresponding to the $3p$ sublevel — the student must draw it in at the appropriate position and relative height.]

Question 2

2021 ▪ Q2

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

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

Question 2

2021 ▪ Q2

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

(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.

Solution 2

(a)(i)

Mark scheme

- The mass spectrum's tallest peak (highest relative abundance, ~92%) is at mass 28, so Si-28 is the most abundant isotope. Silicon's atomic number is 14, so this isotope has 14 protons and $(28 - 14 =)$ 14 neutrons.

(a)(ii)

Mark scheme

- Accept either equivalent form of the ground-state electron configuration of Si: $1s^2 2s^2 2p^6 3s^2 3p^2$, or the noble-gas-core notation $[\mathrm{Ne}] 3s^2 3p^2$.

Solution 2

(b)

Mark scheme

- SiH_4 is composed of discrete molecules, so the only intermolecular forces between SiH_4 molecules are (relatively weak) London dispersion forces. SiO_2, by contrast, is a network covalent solid with strong covalent Si–O bonds extending throughout the entire structure. Because London dispersion forces are much weaker than covalent bonds, SiH_4 boils at a much lower temperature (it is already a gas at 161 K) while SiO_2 remains solid.

Solution 2

(c)

Mark scheme

- $SiH_4(g) \rightarrow Si(s) + 2\,H_2(g)$ (state symbols not required; equation is already balanced).

Solution 2

(d)

Mark scheme

- H2(g) molecules are more highly dispersed (able to move freely and occupy a much larger volume) than Si(s) atoms, and therefore have higher absolute molar entropy. Silicon is a solid, so its atoms are held in fixed positions within the lattice, are far less dispersed, and consequently have lower absolute molar entropy than H2(g).

Solution 2

(e)

Mark scheme

- $\Delta S^\circ_{rxn} = S^\circ_{\text{products}} - S^\circ_{\text{reactants}} = [18 + 2(131)] - 205 = +75$ J/(mol$_{rxn}$ · K), using S°: Si(s)=18, H2(g)=131 (×2 mol), SiH4(g)=205, all in J/(mol · K).

Solution 2

(f)

Mark scheme

- High temperature is required so the reactant SiH4 molecules have sufficient thermal (kinetic) energy to overcome the activation energy barrier of the reaction. A negative ΔG° (thermodynamic favorability) only indicates the reaction is spontaneous, not that it proceeds at an appreciable rate at low temperature — reaction rate is a kinetic property governed separately by activation energy.

Solution 2

(g)

Mark scheme

- The missing peak (representing the Si 3p electrons) should be drawn as the rightmost peak on the spectrum — i.e., at the lowest binding energy (below the existing 1 MJ/mol region), since 3p electrons are Si's outermost/valence electrons and thus the most weakly bound. Its height should reach the second gridline above the horizontal axis, reflecting that the 3p sublevel holds 2 electrons.

Solution 2

(h)

Mark scheme

- The valence electrons of a Ge atom occupy a higher principal energy level/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 attraction between the Ge nucleus and its valence electrons, making them less tightly bound and therefore easier to remove — giving Ge a lower first ionization energy than Si.

Solution 2

(i)

Mark scheme

- $E = h\nu = h\dfrac{c}{\lambda} = (6.626 \times 10^{-34}\ \mathsf{J \cdot s})\left(\dfrac{2.998 \times 10^{8}\ \mathsf{m/s}}{4.00 \times 10^{-7}\ \mathsf{m}}\right) = 4.97 \times 10^{-19}\ \mathsf{J}.$

Question 5

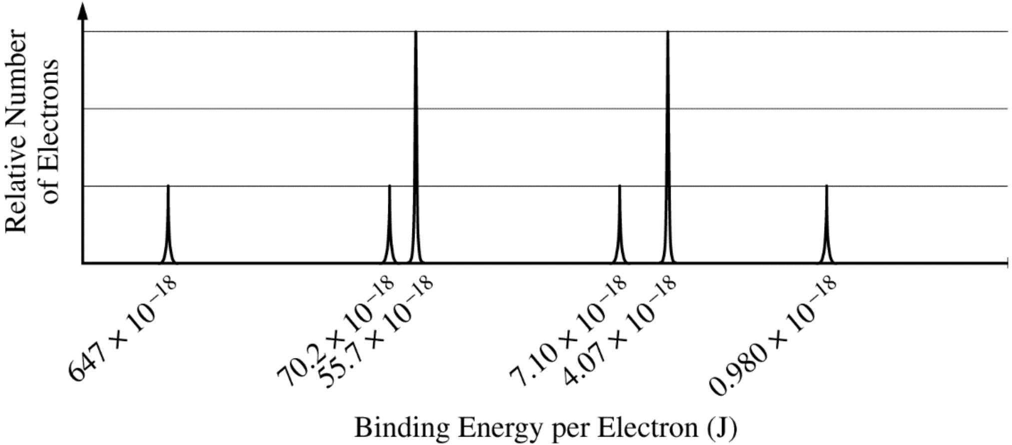
2019 ▪ Q5

The complete photoelectron spectrum of an element in its ground state is represented below.
[Graph: Photoelectron spectrum; y-axis "Relative Number of Electrons" (unscaled, gridlines shown, no numeric values), x-axis "Binding Energy per Electron (J)" plotted with decreasing energy to the right (values labelled at each peak, diagonally, right to left as printed): a short peak at 647×10^{-18}; two adjacent short peaks near 70.2×10^{-18} and 55.7×10^{-18} (the taller of the pair, at 55.7×10^{-18}, reaches near the top of the graph); two adjacent peaks at 7.10×10^{-18} (short) and 4.07×10^{-18} (tall, reaching near the top); and a short peak at 0.980×10^{-18}]
(a)(i) Based on the spectrum, write the ground-state electron configuration of the element.
(a)(ii) Based on the spectrum, identify the element.

Question 5

(b) Calculate the wavelength, in meters, of electromagnetic radiation needed to remove an electron from the valence shell of an atom of the element.

Question 5



Relative Number of Electrons
647 × 10−18
70.2 × 10−18
55.7 × 10−18
7.10 × 10−18
4.07 × 10−18
0.980 × 10−18
Binding Energy per Electron (J)

Solution 5

(a)(i)

Mark scheme

- $1s^2\ 2s^2\ 2p\ \ 3s^2\ 3p\ \ 4s^2$ (equivalently $[Ar]4s^2$). 1 point for the correct ground-state electron configuration, based on the spectrum's six peak groups (binding energies 647, 70.2, 55.7, 7.10, 4.07, 0.980 $\times 10^{\ 1}$ J) with relative heights matching 2,2,6,2,6,2 electrons in the 1s,2s,2p,3s,3p,4s subshells.

Solution 5

(a)(ii)

Mark scheme

- Calcium (Ca), $Z = 20$, consistent with the electron configuration $[Ar]4s^2$ identified in part (a)(i). 1 point for the correct element.

Solution 5

(b)

Mark scheme

- The energy required to remove a valence electron equals the smallest binding energy shown, $E = 0.980\times10^{1}$ J (the 4s electron). 1 point for correctly identifying this as the required energy (may be implicit in the calculation). Using $E = h \ = hc/ \quad = hc/E = (6.626\times10^{3}\ \text{J}\cdot\text{s})(2.998\times10\ \text{m/s})\ /\ (0.980\times10^{1}\ \text{J}) = 2.03\times10\ \ \text{m}$. 1 point for the correct wavelength.