

Topic 1.6: Photoelectron Spectroscopy

Worksheet · AP Chemistry

UNIT 1 · ATOMIC STRUCTURE AND PROPERTIES

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How to Use This Worksheet

Work through the sections in order. Section A checks the ideas, Section B builds fluency in reading spectra, and Section C mixes everything the way an exam would.

Binding energies in this worksheet are simplified teaching values in MJ/mol, as on AP papers. Two habits will carry every question: peak position gives binding energy, peak height counts electrons, and the heights always sum to the total number of electrons.

Do not look at the answer key until you have attempted every question. The key gives full working, so compare your method, not just your final answer.

Section A: Recall and Concepts

A1. Describe how photoelectron spectroscopy works, and write the energy relationship that connects photon energy, binding energy and the kinetic energy of the ejected electron.

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A2. Explain why all the electrons in one subshell appear as a single peak, rather than each electron giving its own peak.

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A3. State what the horizontal position of a peak tells you and what the height of a peak tells you. Which of the two tells you how many electrons a subshell holds?

A4. In one atom, the 1s electrons have a much higher binding energy than the 2s electrons. Give two reasons for the difference.

A5. A student looks at a spectrum and says "the tallest peak must be the 1s peak, because 1s is the most important subshell." Correct the student.

Section B: Core Practice

B1. The spectrum of an element shows three peaks with relative heights 2, 2 and 1, at binding energies of 690, 48 and 7 MJ/mol respectively. Identify the element, write its electron configuration, and label each peak with its subshell.

B2. An element's spectrum has peaks with heights in the ratio 2 : 2 : 6 : 1, in order of decreasing binding energy. Identify the element, and state which peak, the first or the last in that order, corresponds to its valence electron.

B3. List the peaks of aluminium's spectrum in order of decreasing binding energy, with the subshell and the number of electrons for each.

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B4. State how many peaks appear in the spectrum of calcium, and give the ratio of their heights in order of decreasing binding energy.

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B5. Fluorine and neon are neighbours in Period 2. State which element has the higher 1s binding energy, and explain your answer in terms of nuclear charge and shielding.

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B6. A spectrum shows five peaks whose heights correspond to 2, 2, 6, 2 and 5 electrons, in order of decreasing binding energy. Identify the element and write its configuration.

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Section C: Exam Style

C1. The spectrum of an unknown element shows five peaks. In order of decreasing binding energy, their binding energies and electron counts are: 1580 MJ/mol, 2 electrons; 185 MJ/mol, 2 electrons; 95 MJ/mol, 6 electrons; 12 MJ/mol, 2 electrons; 8 MJ/mol, 6 electrons. (a) Identify the element. (b) Write its full electron configuration. (c) State which peak corresponds to the 3p subshell, and explain why its binding energy is lower than that of the 3s peak.

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C2. Elements A and B are in the same period. The 1s peak of A is at a noticeably higher binding energy than the 1s peak of B. State which element has the larger atomic number, and justify your answer. Describe one more difference you would expect between their spectra if A also has one more occupied subshell than B.

C3. Compare the 3p peaks of sulfur and chlorine. (a) State which element's 3p peak sits at the higher binding energy, and why. (b) State which element's 3p peak is taller, and why. (c) State which element's spectrum has more peaks overall, or whether they are equal, and justify your answer.

Answer Key

A1. A sample is irradiated with photons of known, high energy. A photon transfers its energy to a single electron, which is ejected; the instrument measures the ejected electron's kinetic energy. The relationship is: photon energy = binding energy + kinetic energy, so binding energy = photon energy – kinetic energy. Electrons from different subshells have different binding energies, so the spectrum separates them.

A2. Electrons in the same subshell are at the same average distance from the nucleus and experience the same effective nuclear attraction, so they all have essentially the same binding energy. Electrons with the same binding energy are recorded together, as one peak whose size reflects how many of them there are.

A3. Position (on the binding energy axis) tells you how tightly the subshell's electrons are bound. Height (or area) tells you how many electrons the subshell contains: height is proportional to the electron count. It is the height that counts electrons.

A4. First, the 1s electrons are closer to the nucleus, and attraction strengthens sharply as distance falls. Second, the 1s electrons are barely shielded: there is no shell inside them, while the 2s electrons are screened by the 1s pair, so they feel a smaller effective nuclear charge.

A5. Height counts electrons, not importance or energy. The 1s subshell holds only 2 electrons, so its peak is small in height even though it sits at the highest binding energy. The tallest peak is usually a full p subshell, with 6 electrons, such as $2p^6$.

B1. Total electrons = $2 + 2 + 1 = 5$, so the element is boron, B. Configuration: $1s^2 2s^2 2p^1$. Assigning from the highest binding energy: 690 MJ/mol is $1s^2$, 48 MJ/mol is $2s^2$, 7 MJ/mol is $2p^1$.

B2. Total = $2 + 2 + 6 + 1 = 11$ electrons, sodium, Na. The peaks in decreasing binding energy order are 1s, 2s, 2p, 3s. The valence electron is in 3s, the last peak in the order, at the lowest binding energy.

B3. Aluminium (13 electrons, $1s^2 2s^2 2p^6 3s^2 3p^1$) has five peaks. In decreasing binding energy: 1s with 2 electrons, 2s with 2, 2p with 6, 3s with 2, 3p with 1.

B4. Calcium occupies six subshells: 1s, 2s, 2p, 3s, 3p, 4s. Six peaks, with heights in the ratio $2 : 2 : 6 : 2 : 6 : 2$ in decreasing binding energy order.

B5. Neon. Both have the same shielding pattern (the 1s electrons are inside everything else and effectively unshielded), but neon has one more proton, $Z = 10$ against fluorine's 9. The greater nuclear charge pulls the 1s electrons in more strongly, raising their binding energy.

B6. Total = $2 + 2 + 6 + 2 + 5 = 17$ electrons, chlorine, Cl. Configuration: $1s^2 2s^2 2p^6 3s^2 3p^5$.

C1. (a) Total electrons = $2 + 2 + 6 + 2 + 6 = 18$, so the element is argon, Ar. (b) $1s^2 2s^2 2p^6 3s^2 3p^6$, assigned in order from the highest binding energy peak. (c) The peak at 8 MJ/mol, the lowest binding energy of the five, is 3p. Within the same shell, the 3p electrons are on average slightly

farther from the nucleus and more shielded (including by the 3s electrons) than the 3s electrons, so they are held less tightly and have the lower binding energy.

C2. A has the larger atomic number. In the same period the shielding pattern is similar, so the extra protons of the higher Z element pull every electron, including the 1s pair, in more strongly, giving higher binding energies throughout the spectrum. If A has one more occupied subshell, its spectrum will show one additional peak, at the low binding energy (right hand) end of the spectrum, corresponding to that extra outer subshell.

C3. (a) Chlorine's. Chlorine has one more proton than sulfur, with essentially the same shielding, so its 3p electrons feel a stronger effective nuclear charge and are bound more tightly. (b) Chlorine's. Sulfur is $3p^4$ and chlorine is $3p^5$; peak height is proportional to the number of electrons, and $5 > 4$. (c) Equal. Both elements occupy exactly the same five subshells, 1s, 2s, 2p, 3s and 3p, so both spectra have five peaks; they differ in the positions and heights of the peaks, not in their number.

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