Lesson Plan: Introduction to PES

FOR THE TEACHER

Summary
In this lesson students will learn how to interpret simple photoelectron spectroscopy spectra by incorporating their knowledge of electron configurations, periodic trends, and Coulomb’s law.

Grade Level
High School (AP Chemistry)

NGSS Alignment
This activity will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS4-3:** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
- **HS-PS4-4:** Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- **Scientific and Engineering Practices:**
  - Using Mathematics and Computational Thinking
  - Analyzing and Interpreting Data
  - Obtaining, Evaluating, and Communicating Information

AP Chemistry Curriculum Framework
This lesson plan supports the following units, topics and learning objectives:

- **Unit 1: Atomic Structure and Properties**
  - **Topic 1.5:** Atomic Structure and Electron Configuration
    - **SAP-1.A:** Represent the electron configuration of an element or ions of an element using the Aufbau principle.
  - **Topic 1.6:** Photoelectron Spectroscopy
    - **SAP-1.B:** Explain the relationship between the photoelectron spectrum of an atom or ion and:
      - a. The electron configuration of the species.
      - b. The interactions between the electrons and the nucleus.
  - **Topic 1.7:** Periodic Trends
    - **SAP-2.A:** Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity.

- **Unit 3: Intermolecular Forces and Properties**
  - **Topic 3.12:** Photoelectric Effect
    - **SAP-8.B:** Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.

Objectives
By the end of this lesson, students should be able to
- Label the peaks of a PES spectrum and identify the corresponding element.
- Compare radii and ionization energies of elements given PES spectra.
Chemistry Topics
This lesson supports students’ understanding of

- Atomic structure
- Photoelectric effect
- Photoelectron spectroscopy
- Emission Spectrum
- Electrons
- Coulomb’s law

Time
Teacher Preparation: 60 minutes
Lesson: 150 minutes (over the course of 3 periods)

Materials
- Computer and internet access
- Projection capability (if student internet access is limited)

Safety
- No specific safety precautions need to be observed for this activity.

Teacher Notes
- The redesign in 2014 introduced PES to the AP exam. The College Board PES Webcast provides a very helpful primer on PES that was designed to inform teachers as we updated our course materials.
- Below is a list of the PES related questions that have appeared on the AP exam since 2014. You can access the secure exams through your audit page on the College Board website. The operational exams are available through the College Board AP chemistry page. This list is courtesy of Russ Maurer’s annually updated document available at the College Board AP Chemistry Community forum.
  - 2014, secure exam, MC#31
  - 2015, secure exam, FR#6
  - 2015, operational exam, FR#1
  - 2016, secure exam, MC#35, FR#5
  - 2016, operational exam, FR#1
  - 2017, secure exam, MC#19
  - 2018, operational exam, FR#7

- **PES Background Notes:**
- PES has been well received by my students after learning about electron configurations. Some teachers prefer to do PES first, or to do them simultaneously, and those are also good options. The student handouts included with this lesson would need some tweaking for use prior to electron configurations.
- It seems that the most difficult part about teaching PES is clearing up all of the Coulomb’s law misconceptions, but it is a great opportunity for that!
  - At the first introduction of Coulomb’s law, students always think it is simple enough: *Attraction increases as charge increases and attraction decreases as distance between charges increases*. I find that they do really understand it at the math level, but not as much when applied to a chemistry scenario like binding energy, radius, or ionization energy. In addition, students understand that properties like radius are based on attraction and that more attraction means smaller radius. However, getting them to tie it all together can be a challenge.
Every time we use Coulomb’s law I walk them through the same set of steps – define the charges, define the distance between those charges if needed, and then compare the strength of attraction.

For example, when comparing radii of elements in a period, the charges are $Z_{\text{eff}}$ and the valence electrons, both of which increase across a period. Distance between the charges (nucleus and valence) does not change appreciably since all the valence electrons are in the same shell, thus higher charges leads to a stronger attraction and smaller radius.

For group trends in radii, the charges are still $Z_{\text{eff}}$ and the valence electrons, but in a group, $Z_{\text{eff}}$ and the number of valence electrons is the same therefore distance is the key. As the number of filled shells between the nucleus and valence increases, then the distance between the nucleus and valence also increases which decreases attraction (filled shells also means shielding comes into the group trend discussion).

I personally prefer and find that starting explanations with charge, versus distance, is easier since changes in charge tend to be bigger than changes in distance. Think about ion charges scaling by an order of 2 or 3, but distance increases only incrementally. Others have success starting from distance.

I find that going through the whole thought process multiple times at the beginning of the unit on atomic structure is helpful for students since it seems counterintuitive to have higher total charges but also less attraction down a group. Consistently defining charges and distance in this unit is helpful before moving on to attractions between ions and molecules in the next one.

A Few Notes on Binding Energy:

- Binding energy correlates with ionization energy but they are not exactly the same. As you work through PES, it is likely that thoughtful kids will start to wonder about how successive IEs are different for an element but in a PES spectrum all the electrons of a subshell are equal.
- In PES, photons have sufficient energy to eject electrons from many different subshells simultaneously and the resulting KEs of all ejected photoelectrons are measured. So a peak is a cluster of photoelectrons having very similar KEs which then represent a subshell.
- It is also good to note that “intensity” on the y-axis does not mean the same thing as “number of electrons.” Multiple choice question 34 on the 2014 secure exam used a real spectrum with intensity on the y-axis and a lot of noise peaks in the spectrum.
  - There were two, filled 1s peaks of different heights corresponding to the 1s shell of two different elements. Since they were both filled, the height was irrelevant to the question being asked, but the different peak heights could have been a confounding factor for students.

- The PES webinar from the College Board discusses a few real spectra.
- This activity does not include “real” spectra and I do not believe any have appeared on the exam since then, but it might be useful to discuss that example with students.

Lesson Outline:
- Day 1: A Brief Introduction to Photoelectron Spectroscopy
  - Use the supplied student handout, and corresponding answer key.
- Day 1 Resources
  - Khan Academy: Photoelectric Effect
  - PhET: Photoelectric Simulation
  - Khan Academy: Photoelectron Spectroscopy
  - University of Guelph Chemistry: PES spectrum was generated using data from this site and Microsoft Excel

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I recommend reading the included resources before assigning this activity so that you can decide how much your students need to do based on the content of your text or other teaching materials.

The textbook that I use (Chemistry: The Central Science, Brown et al, 9th ed) contains no information about photoelectron spectroscopy so this is designed as a brief reading assignment to provide just enough background to be prepared for the AP exam. If you require students to read the Khan Academy material and tinker with the PhET simulation then this activity could take over an hour. Paring to just the essentials, it could be finished in under 30 minutes.

The Khan Academy readings are correlated to the AP exam LOs and are a great, free resource.

The PhET simulation is perfect for visualizing the photoelectric effect.

If time does not permit exploring these resources in class, they can be assigned for homework.

**Day 2: Exploring PES**

- Use the supplied student handout, and corresponding answer key.
- You should explore this [Photoelectric Spectra (PES) flash file](#) in advance so that you can help the students troubleshoot as needed.
- Since it is a flash file, students may need to use the Firefox browser.
- On macs, they can download a free version of Elmedia player to open the file.
- If the majority of students are using chromebooks, or if internet access is unreliable, then it would be better for you to display the spectra for the students to use. In this method, the entire activity could be done as a whole class discussion if class dynamics allow.
- Alternatively, you could screenshot the relevant spectra and share them with the students by email, LMS, or on paper.
- In the ideal scenario, kids work in small groups of 2 or 3 while you walk the room and facilitate, answering questions or steering discussions as needed. If there seems to be a pervasive issue then you could pause the small group work and clarify points out loud as a whole class before breaking back into group work.

**Day 3: Additional PES Practice**

- Use the supplied student handout, and corresponding answer key.
- Resources
  - [Photoelectric Spectra (PES) flash file](#)
  - Question 3 spectra are pulled from this site
- [University of Guelph Chemistry](#)
  - Question 2 graph and Question 3 data come from this site
  - All other PES spectra were generated using data from this site and Microsoft Excel
- Day 3 of the lesson will depend on the pacing of Day 1 and Day 2.
- Day 3 might open with a follow-up discussion about the “Exploring PES” handout if students did not finish during the class period. If that is the case, then you could start the Day 3 activity with what class time remains and assign the rest for homework. The answers could be discussed on Day 4.
- If students finished the Day 2 activity early, you could hand this out for them to do as homework and then you could go over the questions as a class, or in small groups, on Day 3.
- Alternatively, Day 3 “Additional PES Practice” questions could be divided into short refresher questions to sprinkle throughout subsequent chapters, especially if you are pressed for time.
- This could also serve as a quiz to assess learning across Day 1 and Day 2.
- After spending time working as a whole class and then in small groups, I find it useful to have students work some follow-up problems independently so that they can see how much they really understand without help from classmates. I might assign the first three questions for homework on Day 2 and then go over those at the start of class on Day 3. The students could then work in small groups for the duration of class on the last few problems.