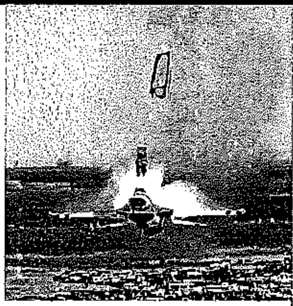


NATIONAL MATH + SCIENCE INITIATIVE

LTF Activity: Eject! Eject!

Examining Electron Energies

MATERIALS

copy of "Eject! Eject!" PES Manipulative, laminated

marker, Vis-à-vis®

PowerPoint™ presentation for "Eject! Eject!"

An electron can absorb the energy from a photon of light bombarding an atom. If substantial enough, the increase in energy contributes to the following:

- Increasing the potential energy of the electron to zero, thereby ejecting it. This is symbolized as the change in potential energy, ΔU_E.
- Providing the electron with kinetic energy (KE) so it can zoom off once free from the attractive force of the nucleus.

Mathematically, the energy of a photon is given as $h\nu$, where h is Plank's constant and ν is the photon's frequency. Therefore,

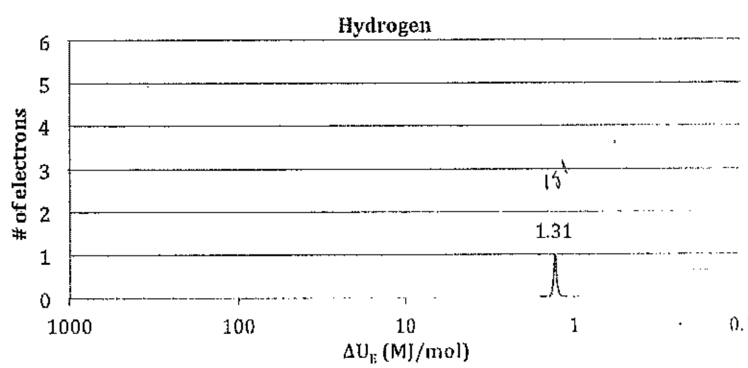
$$h\nu = \Delta U_E + KE_{electron} \quad \text{(Eq. 1)}$$

The analysis of electron energies for an atom via this principle is called **photoelectron emission spectroscopy** (PES).

Let's break that down: A "photoelectron" is an electron that has absorbed the energy from a photon. "Emission spectroscopy" just means that there will be a range, or spectrum, of energies from the emitted photoelectrons. Because only one frequency of photon is used for analysis, electrons with different potential energies in the atom escape with different velocities according to their kinetic energy.

Although a detector is directly measuring the kinetic energy of the photoelectrons, simple algebra allows us to easily plot the ΔU_E. Figure 1 shows the spectrum that resulted from the PES analysis of a hydrogen atom.

Figure 1. PES spectrum for hydrogen



PRE-LAB EXERCISES

1. The electrostatic potential energy, U_E, of the electron bound to the nucleus of a hydrogen atom is approximately −1310 kJ/mol. Carefully consider the units of the axis shown in Figure 2.

   a. Draw and label a solid line representing the potential energy of the hydrogen electron.

   b. Draw and label a dashed line representing the potential energy the electron would have if it were completely ejected from the atom such that the distance between the nucleus and the electron was effectively infinity.

   c. Draw an arrow pointing from the potential energy of the bound electron to the potential energy of the ejected electron.

   d. Label the change in energy, ΔU_E, on your diagram with the appropriate sign, magnitude, and units.

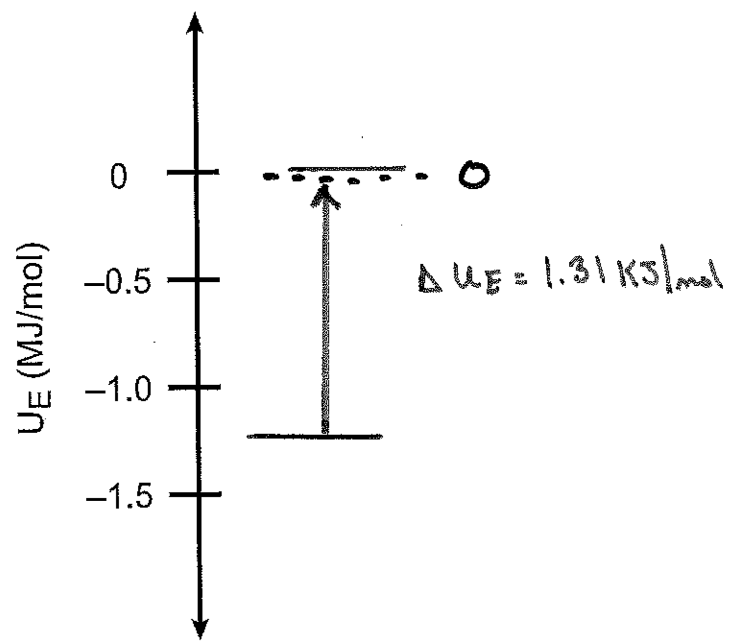


Figure 2. Electrostatic potential energy for electron, U_E

Video on my website →

Photoelectric effect + PhotoElectron Spectroscopy

PRE-LAB EXERCISES (CONTINUED)

2. Go to http://phet.colorado.edu/en/simulation/photoelectric and run the PhET simulation for the photoelectric effect. Select sodium as the element and select the graph of "electron energy versus light frequency."

   Play with the sliders for intensity and type of light. Remember that IR light is low frequency whereas UV light is high frequency.

   a. Based on the graph, state the effect of light intensity on the kinetic energy of the ejected electrons.

   The Intensity changes the # of electrons ejected But not the KE of those electrons (velocity)

   b. Based on the graph, state the effect of light frequency on the kinetic energy of the ejected electrons.

   The KE of ejected electrons ↑ w/ frequency of light

   c. What might account for why not all electrons have the same velocity at the same conditions of intensity and photon wavelength?

   The electrons do not all have the same velocity because Na atoms have electrons w/ different electrostatic potential energies (U_E)

PRE-LAB EXERCISES (CONTINUED)

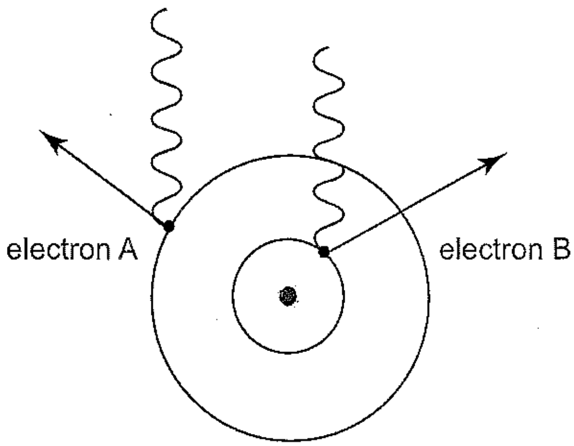


Figure 3. Photons incident on two electrons

3. In the diagram shown in Figure 3, if the two electrons are bombarded with the same wavelength of light, justify which electron:

   a. Has the greater initial U_E

   Electron A has a greater initial U_E because its farther from the nucleus. The force of Attraction is toward the nucleus ∴ U_E ↑ w/ distance

   b. Will experience the greater ΔU_E

   Electron B will experience a greater Δ in U_E. Because it has a lower PE, ∴ requires more energy to eject

   c. Will have the greater escape velocity

   Electron A will have the greater escape velocity Because A is farther out from nucleus, less of the Photon's energy will be used to eject it. Giving Electron A more KE ∴ ($\frac{1}{2}mv^2$) a greater Velocity

PRE-LAB EXERCISES (CONTINUED)

4. Based on your answers provided in Question 3, state the relationship that exists between an electron's U_E and the ΔU_E required to eject it.

The greater the Ue (potential energy), the lower the ΔUE (Δ in energy) to eject it

5. According to the background information:

   a. Rearrange Equation 1 to solve for ΔU_E.

   $h\upsilon = \Delta U_E + KE_{electron}$

   $\Delta U_E = h\upsilon - KE_{electron}$

   b. Circle the term in your equation that is constant for every photoelectron.

   $h\upsilon$

   c. Write your interpretation of the graph in Figure 1 based on your understanding of the axes titles and values.

   Hydrogen Atom has its one electron ejected from the Atom at ΔUE = 1.31 MJ/mol

PRE-LAB EXERCISES (CONTINUED)

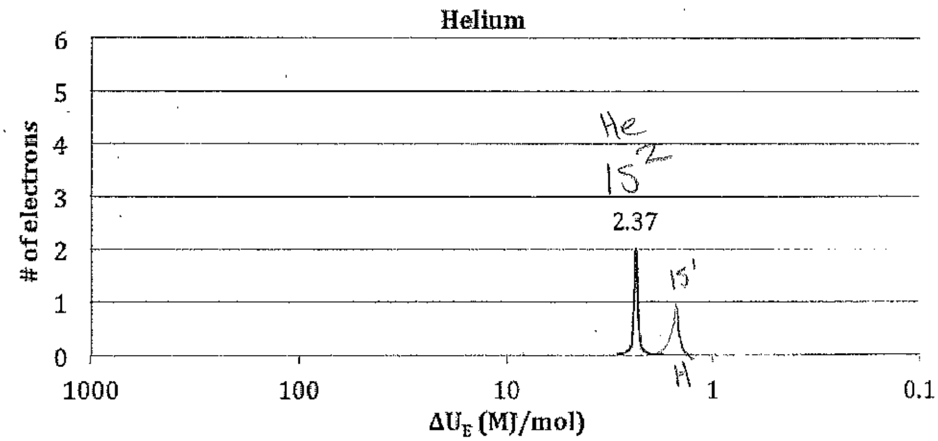
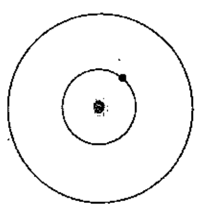


Figure 4. PES spectrum for helium

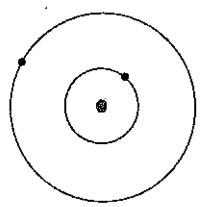
6. Based on the spectrum for helium shown in Figure 4, which model shown best represents the electron arrangement for helium? Justify your choice and state why the graph does not support the other two incorrect models.

I.



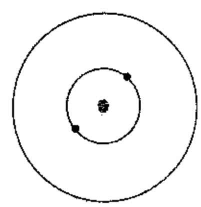
This model would have just 1 electron ejected. But y-Axis shows 2e have Been ejected.

II.



This model would have 2 peaks (blue)

(III) Best Based on Spectrum



Graph shows that 2e ejected at SAme ΔUE.

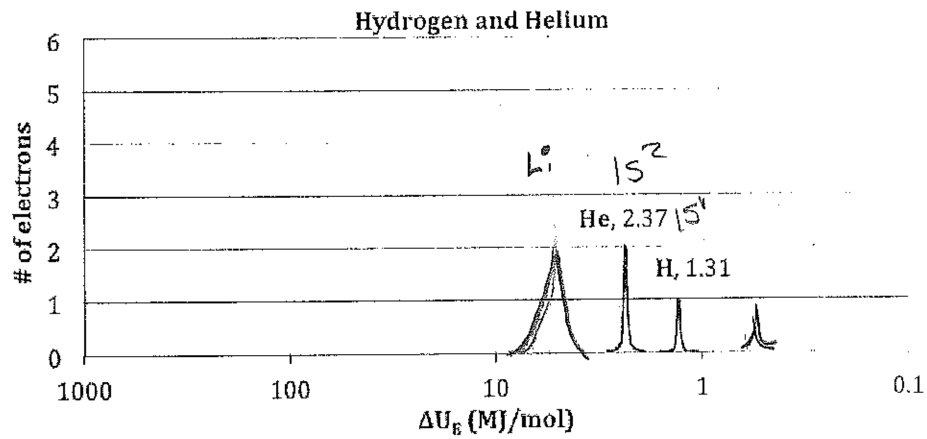
7. Compare and contrast the spectra for hydrogen and helium. What differences in the atomic structure of hydrogen and helium can account for why the values for hydrogen and helium are not the same?

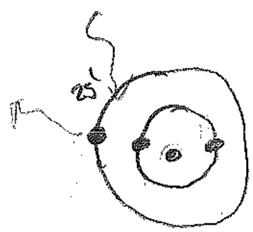
H 1s¹ He 1s²

H has a peak, 1e, at 1.31 MJ/mole, while He has a peak for 2e at 2.37 MJ/mol. Because He has 2 protons vs H 1proton, the Zeff is greater for He & it will require more energy to eject electron in He. ~~This is shown By has~~

PROCEDURE

Figure 5. PES spectra for hydrogen and helium





1. Use the graph showing peaks for hydrogen and helium in Figure 5 to answer the following:

   a. On the graph, predict and draw the expected peak for lithium.

   Li $1s^2 2s^1$

   3 protons

   b. Compare your prediction to the actual lithium spectrum shown by your teacher. State the aspects of lithium's spectrum that you got correct and which needed improvement.

   c. What does the analysis of lithium's spectrum help us understand about electrons in the atom that we did not see from hydrogen or helium?

PROCEDURE (CONTINUED)

2. Your teacher has provided you with a laminated copy of a blank PES spectrum. Pay special attention to the units and scale of each axis.
   a. As your teacher displays the spectrum for lithium, predict and draw the spectrum for beryllium on your blank graph using an erasable marker.

   b. Compare your prediction to the actual spectrum for beryllium now displayed by your teacher. State the aspects of beryllium's spectrum that you got correct and which needed improvement.

3. On your laminated copy of a blank PES spectrum:
   a. Predict and draw the spectrum you would expect for boron.

   b. Compare your prediction to the actual spectrum for boron now displayed by your teacher. State the aspects of boron's spectrum that you got correct and which needed improvement.

   c. What does the analysis of boron's spectrum help us understand about electrons in the atom that we did not see from analyzing the first four elements?

   1st time that [redacted] there are 2 peaks close together in energy. They Both represent the Same energy Level But different "subshells" or "sublevels" within

PROCEDURE (CONTINUED)

Your teacher will now show you the PES data for elements with atomic numbers 6 through 20. You may still be asked to make predictions on your blank spectrum.

PROCEDURE (CONTINUED)

4. Consider the PES spectrum for calcium.

   a. How many energy levels do you observe?

   There are 4 energy Levels evident from the spectrum for Ca

   b. On the back of your laminated copy of a blank PES spectrum is an energy axis. Use a marker to draw and label horizontal lines representing the approximate average potential energy for electrons in each energy level.

   Opps — Print extra!!

   Which energy level has electrons with the greatest potential energy? Which energy level has electrons with the least potential energy?

   Energy Level 4 holds e's w/ greatest PE

   → Energy level 1 holds e's w/ Least PE

   c. Write a conclusion statement about energy levels in an atom based on your graph.

   The energy Levels are not spaced at even intervals. There is a greater difference in Energy Btwn Level 1 & Level 2 than there is Btwn Level 2 + Level 3

5. Consider the patterns you have seen in the PES spectra for the first 20 elements.

   a. How do you expect the spectrum for scandium to be different than calcium? Explain.

   Spectrum will Begin a new peak at a lower BE than the peak representing the first 2e's of the 4th energy level

   b. Compare your prediction to the actual spectrum for scandium now displayed by your teacher. State the aspects of scandium's spectrum that you got correct and which needed improvement.

   First time that a new peak has occurred at a greater BE than the sublevel, or subshell, peak that was present in the previous element. In this case, the subshell from the 4th energy level is still @ the lowest BE despite the Addition of an e in new subshell

   c. What does the analysis of scandium's spectrum help us understand about electrons in the atom that we did not see from analyzing the first 20 elements?

   Have now seen that the 3rd energy Level, or shell, has a 3rd peak. This indicates a 3rd subshell, or subshell, which is very Close in energy to the 1st subshell of the 4th energy Level

DATA AND OBSERVATIONS

CONCLUSION QUESTIONS

1.

Table 1. Configuration Coding	
Element	**Electron Configuration**
H	$1s^1$
He	$1s^2$
Li	$1s^22s^1$
Be	$1s^22s^2$
B	$1s^22s^22p_1$
C	$1s^22s^22p^2$
N	$1s^22s^22p^3$
O	$1s^22s^22p^4$
F	$1s^22s^22p^5$
Ne	$1s^22s^22p^6$
Na	$1s^22s^22p^63s^1$
Mg	$1s^22s^22p^63s^2$
Al	$1s^22s^22p^63s^23p^1$
Si	$1s^22s^22p^63s^23p^2$
P	$1s^22s^22p^63s^23p^3$
S	$1s^22s^22p^63s^23p^4$
Cl	$1s^22s^22p^63s^23p^5$
Ar	$1s^22s^22p^63s^23p^6$
K	$1s^22s^22p^63s^23p^64s^1$
Ca	$1s^22s^22p^63s^23p^64s^2$
Sc	$1s^22s^22p^63s^23p^63d^{14}s^2$

CONCLUSION QUESTIONS (CONTINUED)

2. As you found, the energy of the 3*d* sublevel, or *subshell*, is very close in energy to the 4*s* sublevel. The same phenomenon is noted in higher energy shells. This can sometimes lead to transition metal electron configurations that are different from what we can predict, as electrons are arranged to minimize electron repulsion and maximize attraction.

   Look at your electron configurations and the periodic table. To the best of your ability, predict configurations for the following atoms:

   a. Cr [Ar] $4s^2 3d^4$

   b. Zn [Ar] $4s^2 3d^{10}$

   c. Ga [Ar] $4s^2 3d^{10} 4p^1$

   d. Kr [Ar] $4s^2 3d^{10} 4p^6$

3. When atoms become cations, they always lose electrons with the greatest potential energy. Based on the PES data for scandium, write the electron configuration for the following ions:

   a. Sc^{1+} [Ar] $4s^{1} 3d^1$

   b. Sc^{2+} [Ar] $4s^{0} 3d^1$

   c. Sc^{3+} [Ar] $4s^{0} 3d^{0}$

4. When atoms become anions, they add electrons that have the greatest potential energy. To the best of your ability, predict configurations for the following ions:

   a. N^{3-} $1s^2 2s^2 2p^6$

   b. Cl^- [Ne] $3s^2 3p^6$

   c. O^{2-} $1s^2 2s^2 2p^6$

CONCLUSION QUESTIONS (CONTINUED)

5. The *first ionization energy* is defined as the least amount of energy required to remove an electron from an atom in the gaseous phase.

   a. Look at the PES spectrum for chlorine shown in Figure 6. Circle the peak that contains the first electron that would be removed from the atom and state the ionization energy in units of kJ/mol.

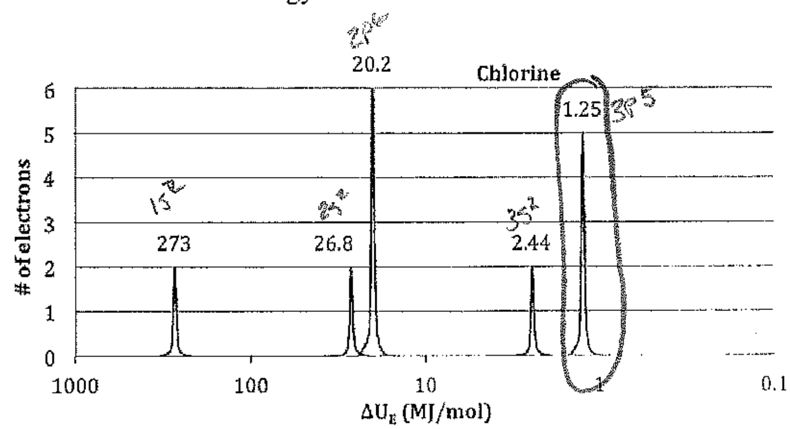


Figure 6. PES spectrum for chlorine

$\left(\frac{1.25\ MJ}{mol}\right)\left(\frac{1000\ kJ}{1\ MJ}\right) = 1250\ \frac{kJ}{mol}$

   b. Look at the graph shown in Figure 7. Describe the general trend for first ionization energies as you move from left to right across the period, and note any exception(s) to the trend.

2nd Period	Li	Be		B	C	N	O	F	Ne

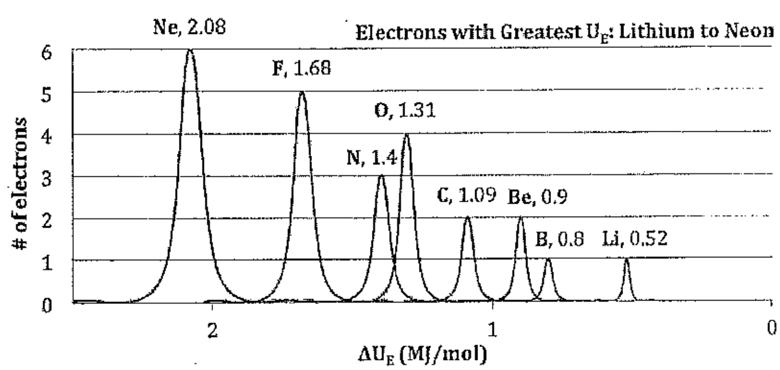


Figure 7. Electrons with greatest U_E, lithium to neon

The ionization energy increases as you move from Left to Right across the 2nd period from Li to Ne.

2 exceptions in General Trend

* Boron has a smaller IE than Be
* O has a smaller IE than N

CONCLUSION QUESTIONS (CONTINUED)

6. Propose an explanation that would account for the general trend in first ionization energies across a period. Consider what you know about Coulomb's law.

As you go Left to Right in period # protons ↑.
Because e & p are oppositely charged, the PE will Be negative
As p↑, the magnitude of Ratio ↑ ⇒ more negative, or smaller value of UE. ∴ electrons in Ne require greater Δ of Energy to Be ejected.

7. Once the first electron has been removed (first ionization energy), other electrons in the valence shell move in closer to the nucleus as a result of the increased proton to electron ratio. According to this information, predict whether an atom's *second ionization energy* is greater than, less than, or equal to its first ionization energy.

→ Radius gets smaller, after 1st electron Removed.

This means that the 2nd electron to be Removed is will have a lesser electrostatic PE. (wether in same Energy level or one Below it)

2nd electron Being Removed will Be closer/more Bound to nucleus. ∴ Require more energy to Remove it.