AT Chemistry

POGIL on Photoelectron Spectroscopy

Background Information

Photoelectron spectroscopy is very similar to the photoelectric effect, except that photons are used to knock electrons out of atoms in the gas phase instead of from the surface of a metal. These electrons are called photoelectrons. And because electrons are usually less easily removed from the atoms of other elements than they are from the atoms of metals, very-high-energy photons such as the photons of very-short-wavelength ultraviolet radiation or even X-rays must be used. If the energy of the photon is greater than the ionization energy of the electron, the excess energy appears as kinetic energy, $1/2mv^2$, of the electron, which is ejected from the atom with a speed v. In other words, the speed of the ejected electron depends on how much excess energy it has received. So, if IE is the ionization energy of the electron and KE is the kinetic energy with which it leaves the atom we have

$$E_{photon} = h\nu = IE + KE$$

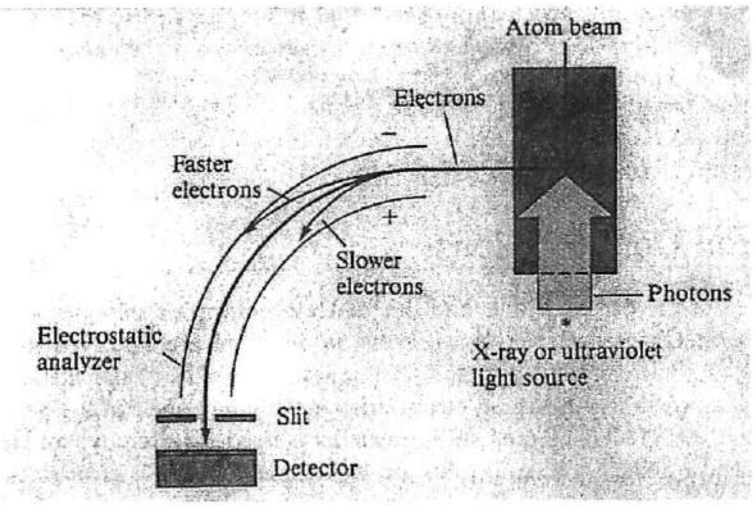
Rearranging this equation gives

$$IE = h\nu - KE$$

Question

If a particular atom is hit with a photon energy (hν) of 143.4 MJ/mole, and the kinetic energy (KE) of the ionized electron is 114.8 MJ/mole, calculate the ionization energy of the electron:

Hence we can find the ionization energy IE if we know the frequency or wavelength of the photon-electron. The kinetic energy of the photon is measured in the photoelectron spectrometer illustrated below:

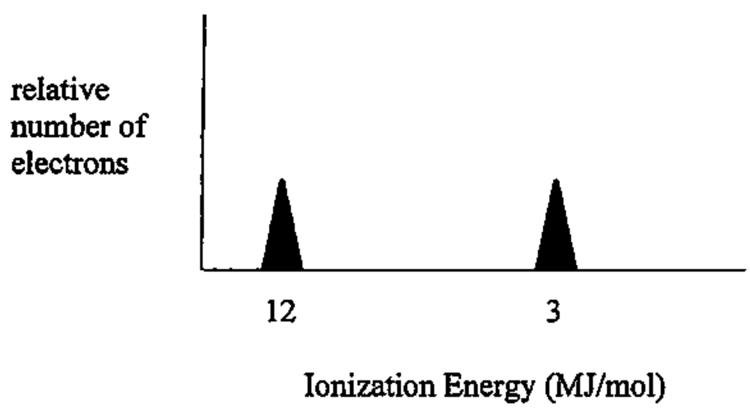


A beam of atoms is irradiated with ultraviolet light or X-rays of a known frequency. The kinetic energies of the ejected electrons are measured by passing them into an electrostatic analyzer which consists of two curved plates, one charged positively and the other negatively. The electric field between the plates deflects each electron into a curved path, the curvature depending upon the speed and therefore the kinetic energy of the electron. Thus only electrons of one particular speed and therefore one particular kinetic energy will have a path of just the right curvature to pass right through the analyzer and through the slit to reach the detector. The detector counts the electrons as they arrive. By varying the charges on the plates, that is, the voltage between the plates, electrons of different energies can be detected.

Keep in mind that if you "zap" a sample of atoms of an element with an energy (hv) that **ionizes all** of the electrons, the photoelectron spectrograph will separate these electrons

- Based on their ionization energies, reflecting the principle energy levels of these electrons
- Gives a relative number of electrons having those ionization energies

The results of a photoelectron spectroscopy experiment can be presented in a photoelectron spectrum. This is essentially a plot of the number of ejected electrons (y axis) as a function of ionization energy (x axis). Below is a sample photoelectron spectrum of some element:



Questions

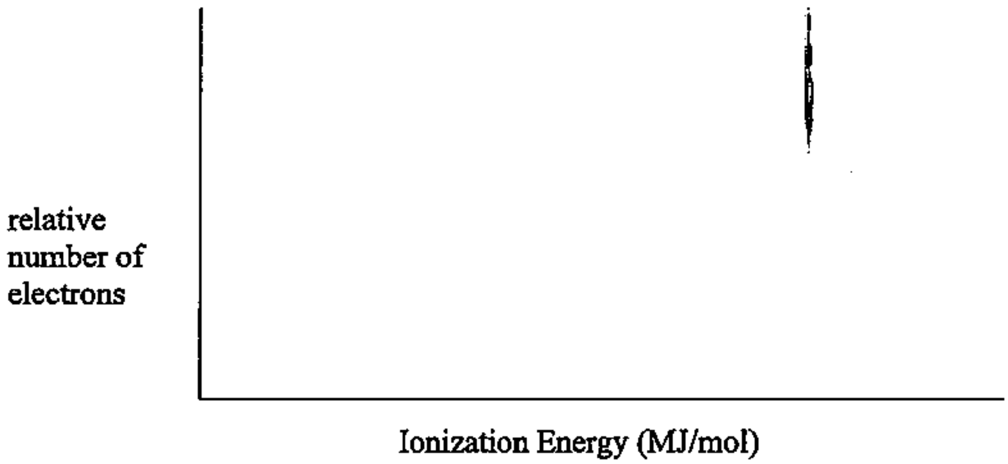
1. What determines the height (intensity) of each peak in a photoelectron spectrum?

2. What determines the number of peaks on the x axis?

3. What determines the position of each peak on the x-axis?

4. In the graph above, what is indicated by the decrease in ionization energy from left to right along the x-axis?

5. Based on the electron configuration of a neon atom, predict and sketch the photoelectron spectrum using the axis below:



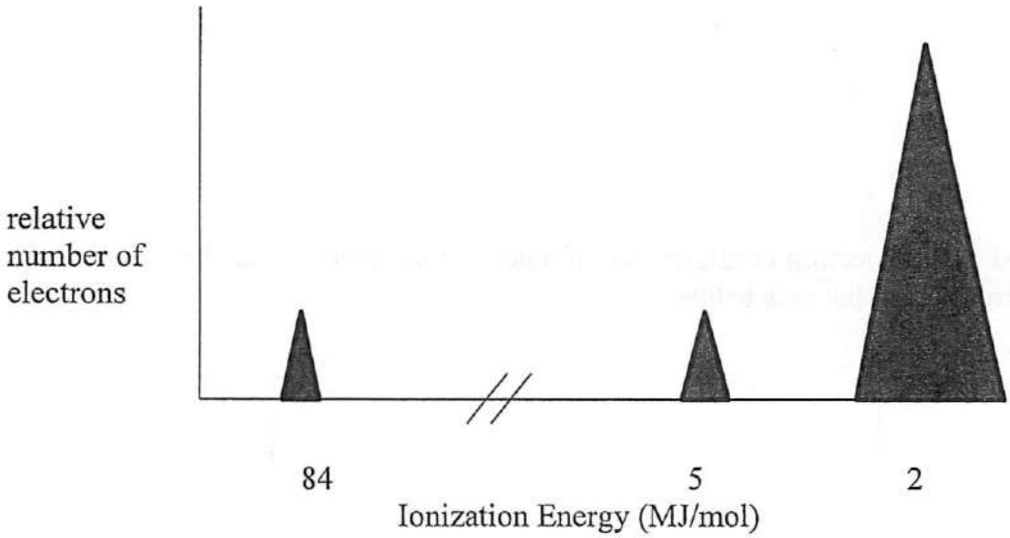
a) On what basis did you predict the number of peaks shown in your spectrum?

b) On what basis did you predict the height of each peak in your spectrum?

A little chemistry humor…

Two electrons met at Starbucks for a cup of coffee. Electron 2s1 started complaining to electron 2s2 and after a while electron 2s2 said "I'm leaving, you're too negative!" To which electron 2s1 replied, "I'm repelled by you anyway!"

6. The actual photoelectron spectrum of neon is illustrated below:

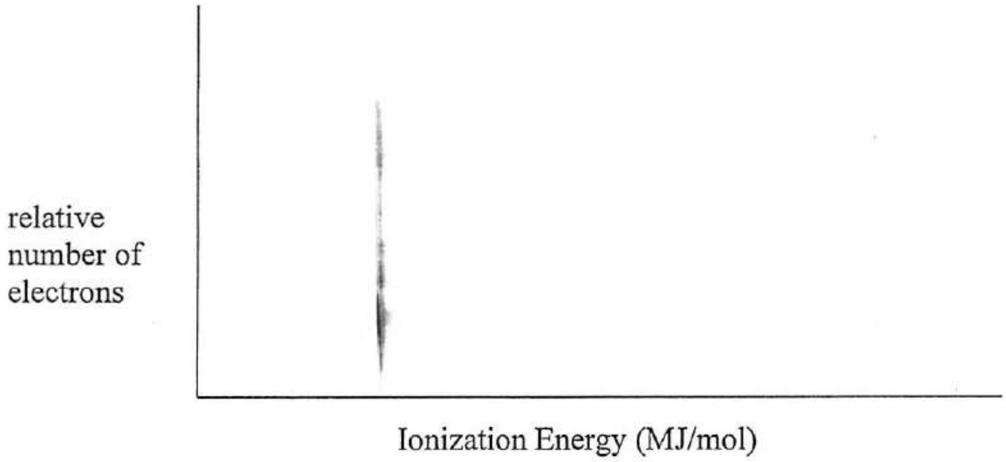


a) Compare and contrast your predicted spectrum for neon with the above observed spectrum.

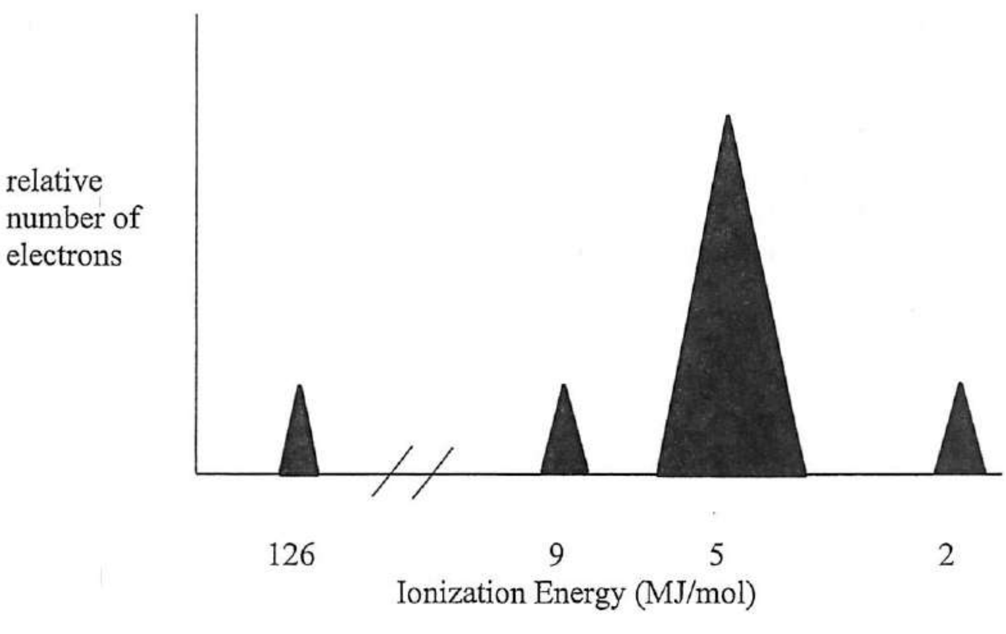
b) Explain the significance of the size and position on the x-axis of the peak at 2 MJ/mol.

7. Sketch the photoelectric spectrum of a carbon atom below, given the following ionization energies (MJ/mol):

   1s: 29   2s: 2   2p: 1



8. What element do you think would give rise to the photoelectron spectrum shown below: Explain your reasoning.



9. Indicate whether each of the following statements is true or false and explain your reasoning:

   a) The photoelectron spectrum of Mg^{2+} is expected to be identical to the photoelectron spectrum of Ne.

   b) The photoelectron spectrum of Cl-35 is identical to the photoelectron spectrum of Cl-37.

10. The energy required to remove a 1s electron from F is 67.2 MJ/mole. The energy required to remove a 1s electron from Cl is

    a) 54 MJ/mole
    b) 67.2 MJ/mole
    c) 273 MJ/mole
    d) A 1s electron cannot be removed from Cl

    Explain.

References:

Moog & Farrell, Chemistry: A Guided Inquiry, 2002, John Wiley & Son
http://www.chem.arizona.edu/chemt/Flash/photoelectron.html