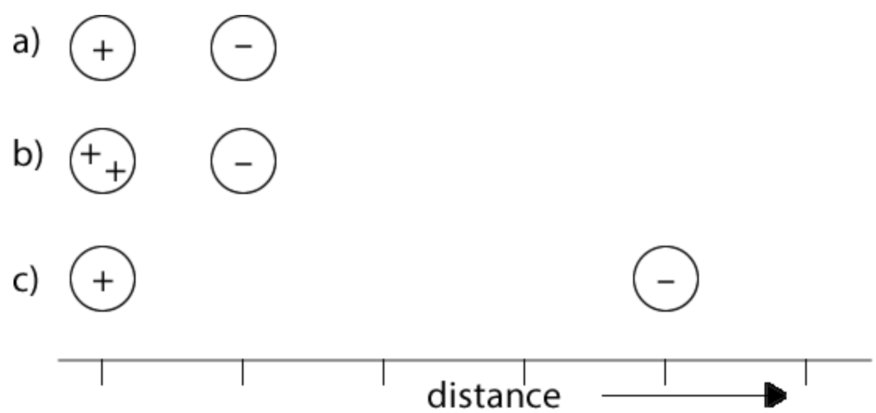
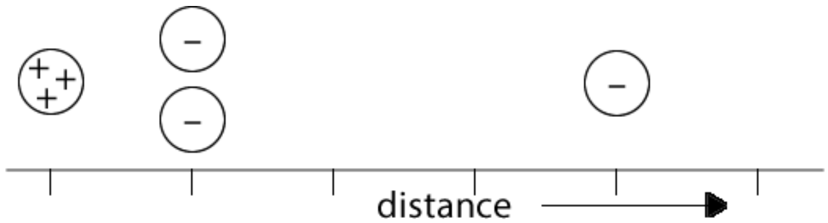
PART I: Discovering how electrons are 'arranged' in an atom

1. Describe the nature of the interaction between protons and electrons in an atom? Consider using some or all of the following terms in your description:
   - attraction, repulsion, neutral, positive, negative, charge, distance, nucleus, force, energy, Coulomb's Law.

2. For each situation below, compare the relative energy necessary to separate positive and negative electrical charges.
   - Compare A to B
   - Compare A to C



3. Consider



- How many electrons do you see in the picture? How many protons?
- Which of these electrons is the easiest (requires the least amount of energy) to remove (ionize)? Justify your answer.
- Compare the energy required to remove the electron from 3 with the energy in
    - 2a
    - 2c

The first ionization energy is defined as the minimum energy that must be added to a neutral atom, in the gas phase, to remove an electron from that atom.

This definition can be represented by the following chemical equation:

$$\text{energy} + A(g) \rightarrow A^{+}(g) + e^{-}$$

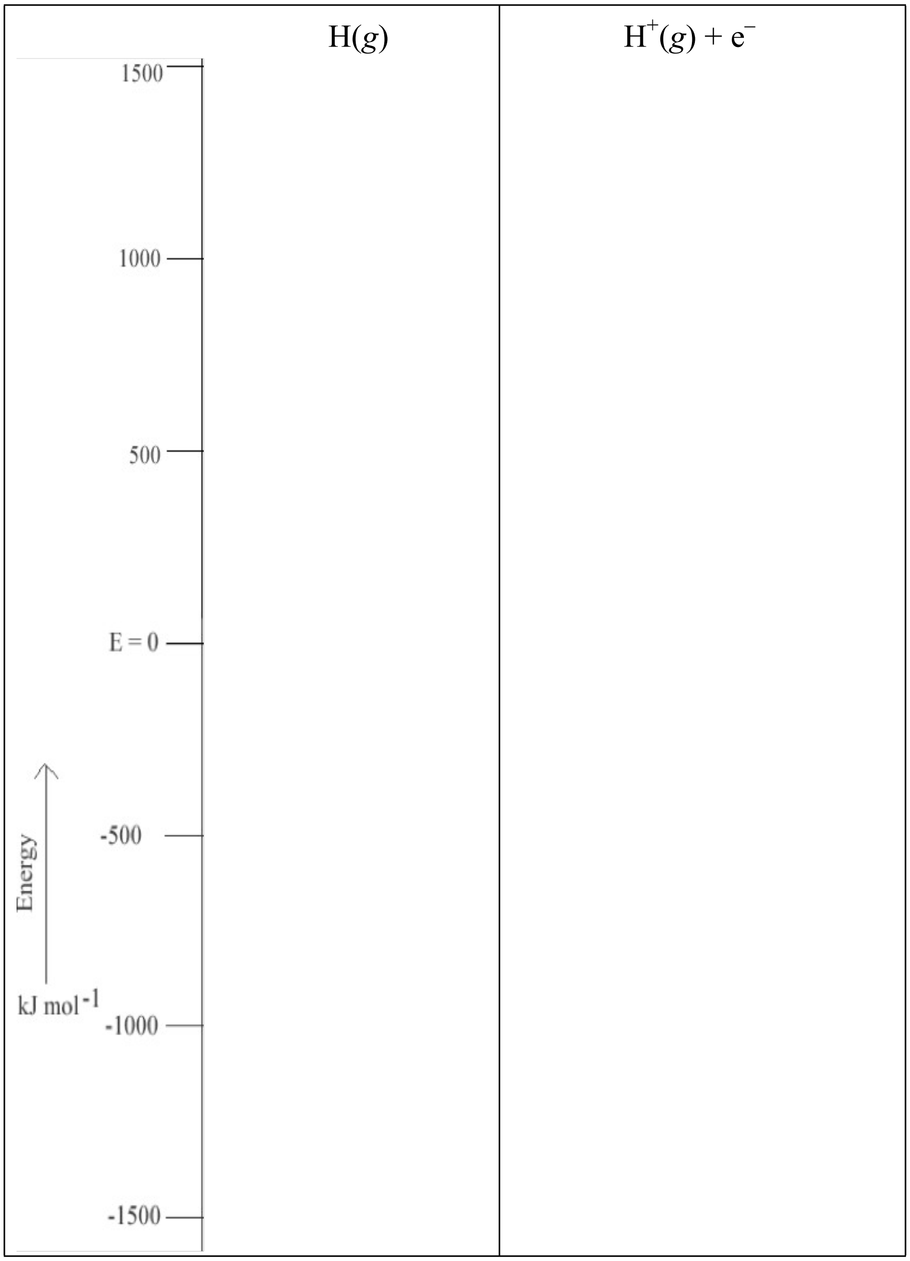
4. In the ionization equation above identify which species is at lower energy, A(g) or $A^{+}(g) + e^{-}$? Justify your answer.

5. Explain why energy is required (an endothermic process) to remove the electron in a neutral atom.

6. The value of the first ionization energy for hydrogen is 1312 kJ mol^{-1}.

$$\text{energy} + H(g) \rightarrow H^{+}(g) + e^{-}$$

   On the graph on the next page use a short horizontal line to indicate the energy of H(g) and a short horizontal line to indicate the energy of $H^{+}(g) + e^{-}$. Be sure to consider your responses to Q4 and Q5 above.



7. What does the difference in energy in the lines in your diagram above represent?

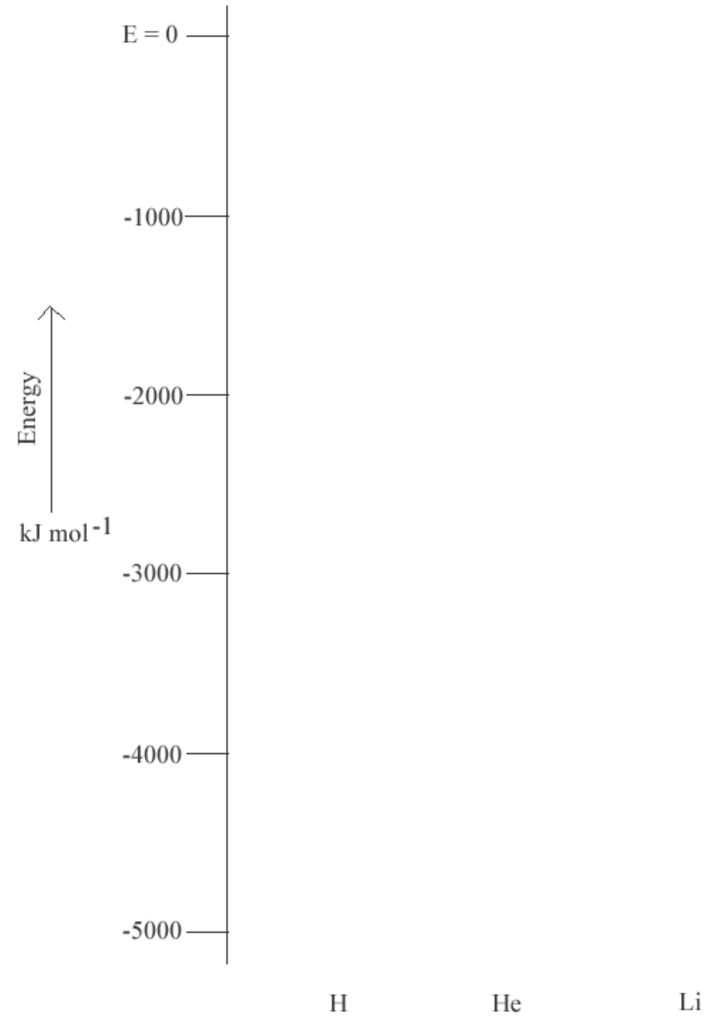
The values for the first ionization energy for a hydrogen and helium atom are provided in the table below.

Atom	$_{1}$H	$_{2}$He	$_{3}$Li
Ionization Energy (kJ mol $^{-1}$)	1312	2373	

8. Based on comparisons you made in Question 2 how would you explain the difference in the values for the first ionization energy for hydrogen and helium?

9. How does your explanation account for the relative charge on hydrogen and helium and the distance of the electron(s) from the nucleus?

In the energy diagram below locate (draw a horizontal line) the first ionization energy for hydrogen and the first ionization energy for helium.



10. How does the diagram illustrate the relative ease with which an electron can be removed from each atom?

11. ***Predict*** a value for the first ionization energy for lithium.

    Do not add your prediction to the figure just yet. Justify your prediction (look back at Question 2 if you need guidance).

The actual value of the first ionization energy of lithium is 520 kJ mol^{-1}. Add this value for to the figure on the previous page.

12. How would you explain the ionization energy for lithium compared to the ionization energy for helium? Compared to hydrogen?

13. ***Predict*** the relative value of the energy necessary to remove a second electron (called the second ionization energy) from lithium. Support your prediction with an explanation.

14. Based on the first ionization energies for hydrogen, helium and lithium that you represented in the figure on the previous page, what can you infer about the distance of the electrons from their respective nuclei.

The first ionization energies for selected elements from the second period of the periodic table are provided in the table below.

Atom	$_3$Li	$_4$Be	$_6$C	$_7$N	$_9$F	$_{10}$Ne
Ionization Energy (kJ mol^{-1})	520	899	1086	1302	1681	2081

15. Explain the trend in ionization energies in terms of the charge of the nucleus and the relative location of the electrons.

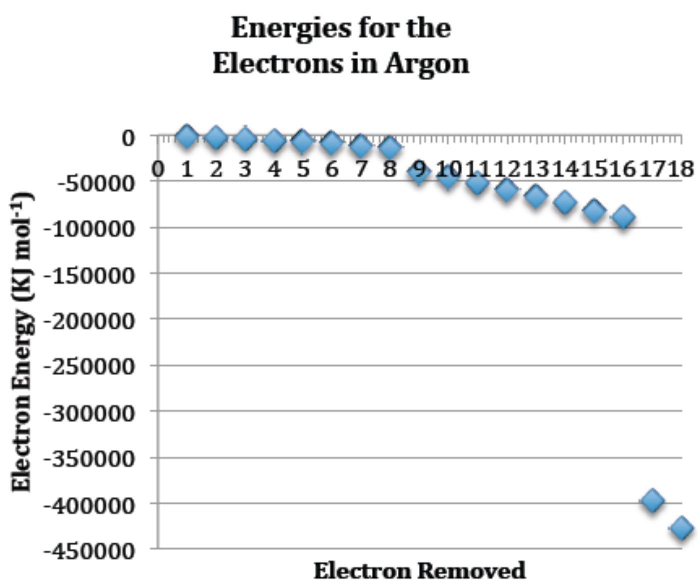
The first ionization energy for the element sodium is given in the following table.

Atom	$_{11}$Na	$_{12}$Mg	$_{14}$Si	$_{15}$P	$_{17}$Cl	$_{18}$Ar
Ionization Energy (kJ mol^{-1})	520					

16. ***Predict*** the values for the first ionization energy for the other selected third period elements. Explain how you arrived at your predictions.

Below is a table containing the electron energies for ***each*** of the 18 electrons in an argon atom. The graph of this data is shown.

Electron Removed	Electron Energy (kJ mol^{-1})
1	–1521
2	–2666
3	–3931
4	–5751
5	–7238
6	–8781
7	–11995
8	–13842
9	–40760
10	–46186
11	–52002
12	–59653
13	–66198
14	–72918
15	–82472
16	–88576
17	–397604
18	–427065

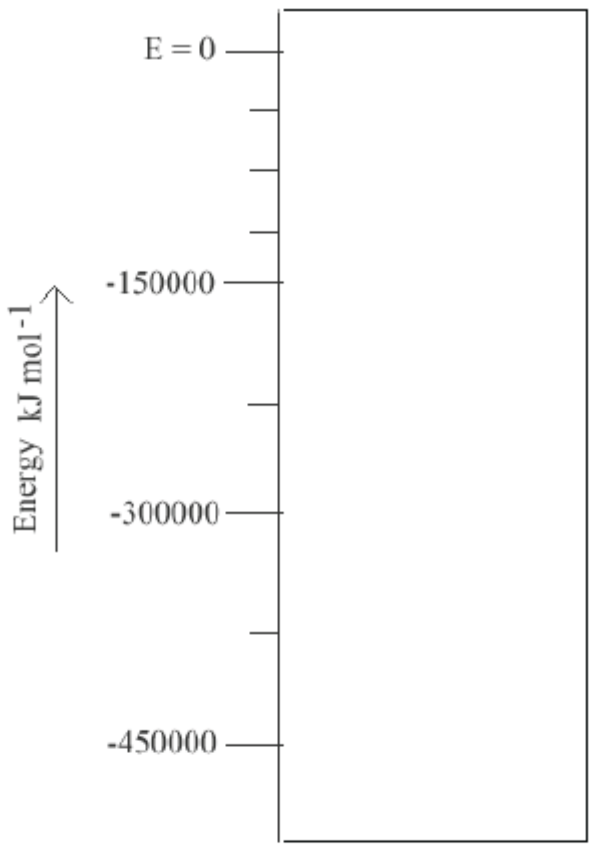


17. Make observations about the graph in terms of the relative energies of the electrons and their relationship to each other.

18. Based on your responses from the previous questions how many ‘groups’ (levels or shells) of electrons are shown for Argon?

19. Indicate the number of electrons in each group/level that you identified?

20. On the graph below draw a horizontal line (to the right of the y-axis) that represents an average energy level for each of the groups of electrons that you identified. Label the levels 1, 2, etc.… beginning from the lowest energy level. What do these lines represent?



21. How would you describe the relative energy separation of these energy levels?

22. An electron from which level requires
- the ***least*** amount of energy to remove?
- The largest amount of energy to remove?

Describe the electron structure (location of the electron) of the atom. Consider using some or all of the following terms in your description; nucleus, electron, energy, distance, level, proton, shell, arrangement, attraction, repulsion, positive, negative, charge, location.

PART II: Do all electrons in the same level have the same energy?

One important conclusion based on the first ionization energy experimental data is that electrons in higher shells require less energy to remove. We have examined experimental data that relates the energy required to remove an electron to the shell the electron occupies.

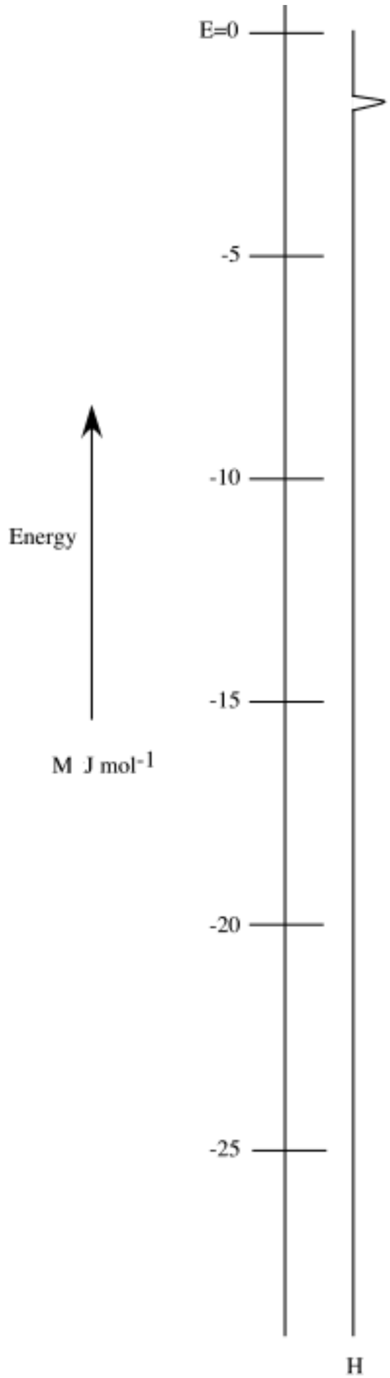
- In which shell does an electron require more energy to remove, an electron in the second shell or the fourth shell?

An interesting question that cannot be answered from the experimental data of the first ionization energy is…

Do all electrons in the same shell require the same amount of energy to remove?

We CAN answer this question if we look at photoelectron spectroscopy (PES) data for the atoms. In a photoelectron spectroscopy experiment any electron can be ionized when the atom is excited. Like with the first ionization, only one electron is removed from the atom. However in a PES experiment it can be ANY electron, not just the electron that requires the least amount of energy to remove.

Examine the PES spectrum for hydrogen shown in the figure. The label on the **y**-axis is energy and the units are in megajoules($M\ J\ mol^{-1}$)



1. What does the **x**-axis depict? Explain.

2. What is the relationship between the photoelectron spectrum and the first ionization energy for hydrogen?

Helium is next, but before looking at its photoelectron spectrum answer the following questions:

3. How many electrons does helium have in its first shell?

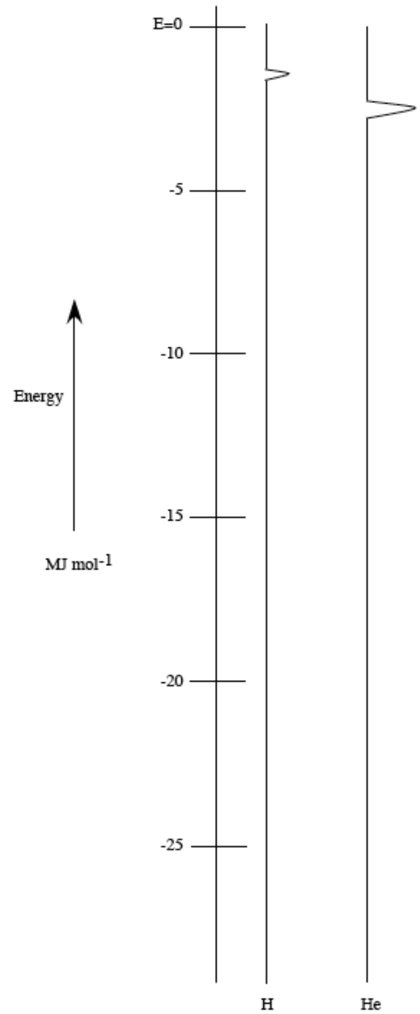
4. Refer back to Part I of this activity, and obtain the first ionization energy for a helium atom. Can you predict what the PES would look like if

    a. the same amount of energy is required to remove each of the electrons?

    b. different amounts of energy are required to remove each electron?

Go to back to the previous figure and sketch ***both*** scenarios.

Examine the PES for helium and compare it to your prediction from the previous question.

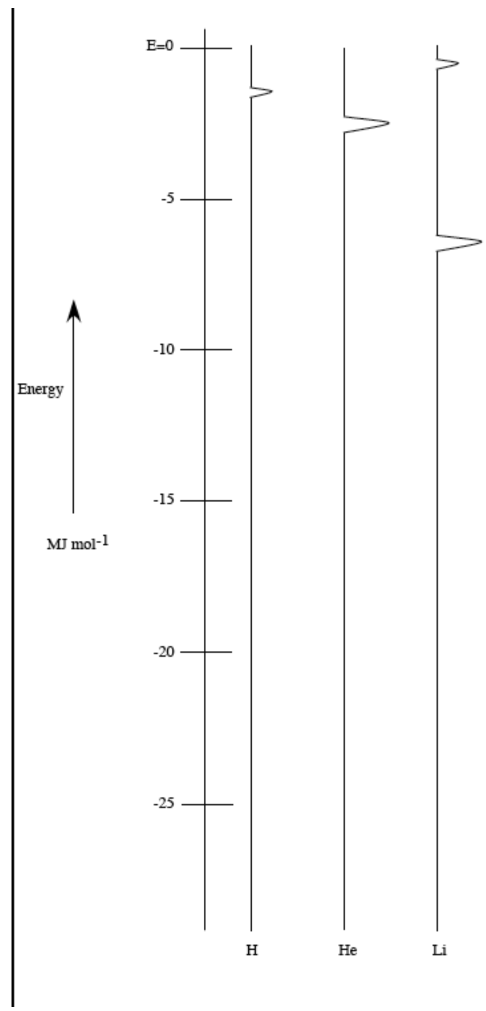


5. Explain the relative energy of the peak(s) and the number of electrons represented by each peak in the PES for helium and for hydrogen.

6. For lithium
   a. How many electrons does lithium have?

   b. What shells (levels) do those electrons occupy?

7. Predict what you expect the PES for lithium to look like. (Note: you do not have to predict the exact energies of each electron, you can make a reasonable estimate based on the first ionization energies for lithium and helium - refer back to Part I of this activity.



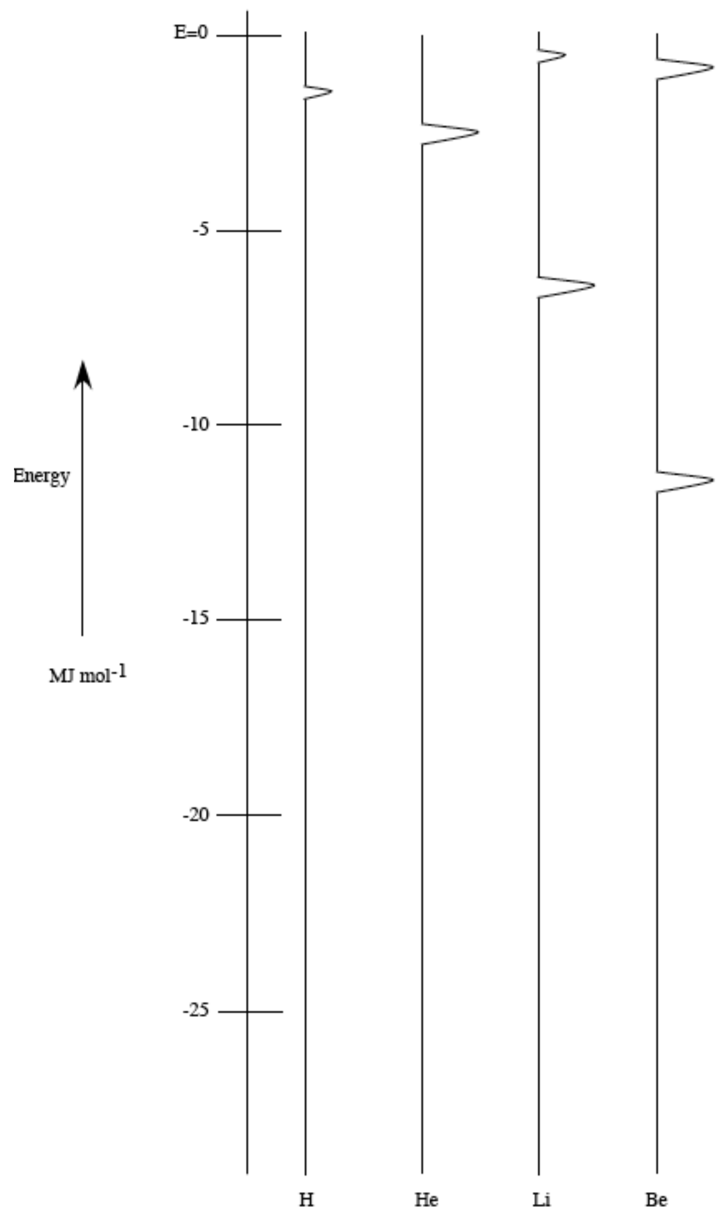
Look at this PES and compare it to the prediction you made in the previous question.

8. For each peak in the PES of lithium, identify the shell the electrons represented by that peak occupy. Be sure to comment about the relative energy of the peak(s) and the number of electrons for each peak for Li.)

The next element in the Periodic Table is beryllium.

9. How many electrons does beryllium have and what shells do those electrons occupy?

10. For the PES for beryllium predict
    a. how many peaks
    b. the number of electron for each peak
    c. estimate the relative energies.



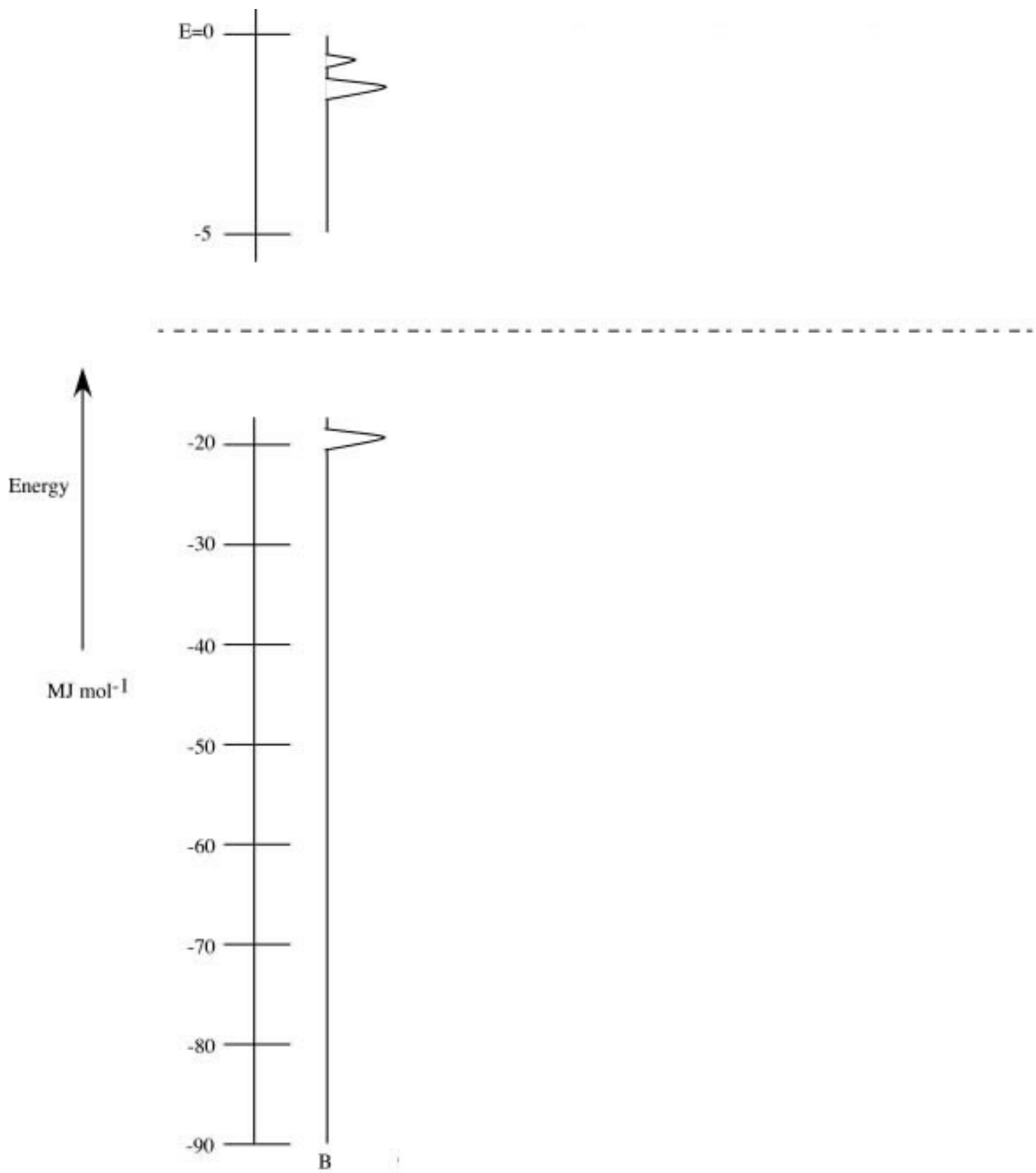
The next element in the Periodic Table is boron.

11. How many electrons does boron have and what shells do those electrons occupy?

12. For the PES for boron predict
    a. how many peaks
    b. the number of electron(s) for each peak
    c. estimate the relative energies

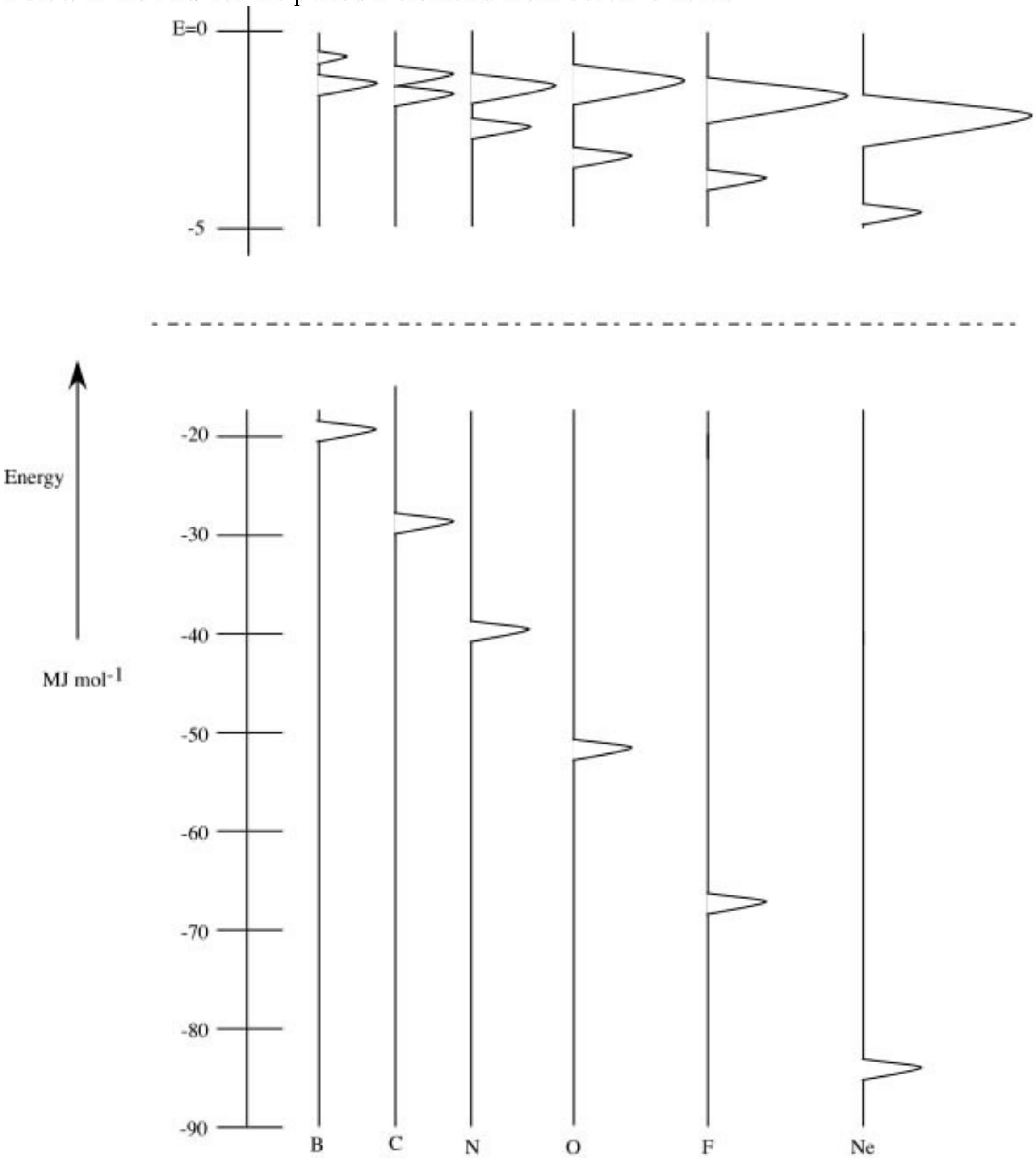
Below is the PES for boron.

13. Briefly describe how to interpret the PES for boron.



14. Predict what changes in the PES you would expect to see going across period 2 of the periodic table, from carbon to neon? Look at the PES for these second period elements.

Below is the PES for the period 2 elements from boron to neon.



Adapted and modified from John Gelder's DRAFT VERSION.

15. Answer the following questions after looking at the PES for hydrogen through neon.
    a. Would you agree or disagree with the following statement? Explain your answer.
       'The electrons in the second shell all have the same energy.'

    b. How many 'subshells' are found in the second shell?

    c. How many 'subshells' are found in the first shell?

    d. How many electrons are in each subshell in the second shell? In the first shell?

    e. Moving systematically from lithium to neon;
        i. How many electrons are in the first shell?

        ii. What happens to the energy required to remove an electron in the first shell moving from left to right in the second period? Support your observation with an explanation.

        iii. What happens to the energy of the electrons in the outer most shell?

16. Look at the PES for the elements in the third period (sodium – argon) and describe your observations. Any surprises? Explain.

A notation has been agreed upon for writing an electron configuration to identify the location of the shell and subshell of each electron in an atom. Shells are labeled with a number; 1, 2, 3, etc. and subshell are labeled with letters; ***s***, ***p***, ***d***, and ***f***. Every shell contains an ***s*** subshell.

17. Write the complete electron configuration for the first ten elements in the periodic table?

Look at the PES for potassium, calcium and scandium.

18. Explain what happens in the PES for scandium that has not occurred in any element prior.

19. If one electron is removed from scandium, which electron (identify the shell and subshell) requires the least amount of energy to remove?