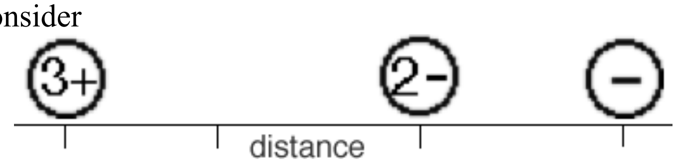
During Class Invention

Question: How are electrons '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. Compare the relative energy necessary to separate positive and negative electrical charges in the following situations? Compare a and b, then compare a and c.

3. Consider



a) how many electrons do you see in the picture? How many protons?

b) which of these electrons is the easiest (requires the least amount of energy) to remove (ionize)?

c) Explain your response in b.

d) compare the energy from 3b with the energy in 2a and then in 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 an atom. This definition can be represented in the following chemical equation;

$$\text{energy} + A(g) \rightarrow A^{+}(g) + 1e^{-}$$

4. In the ionization equation above, which is at lower energy? A(g) or A^{+}(g) and $1e^{-}$? Which is at higher energy? A(g) or A^{+}(g) and $1e^{-}$? Explain.

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}. In the graph below use a short horizontal line to indicate the energy of H(g) (reactant) and a short horizontal line to indicate the energy of H^{+}(g) + $1e^{-}$ (product). (NOTE: Be sure to consider your responses to Q4 and Q5 above.)

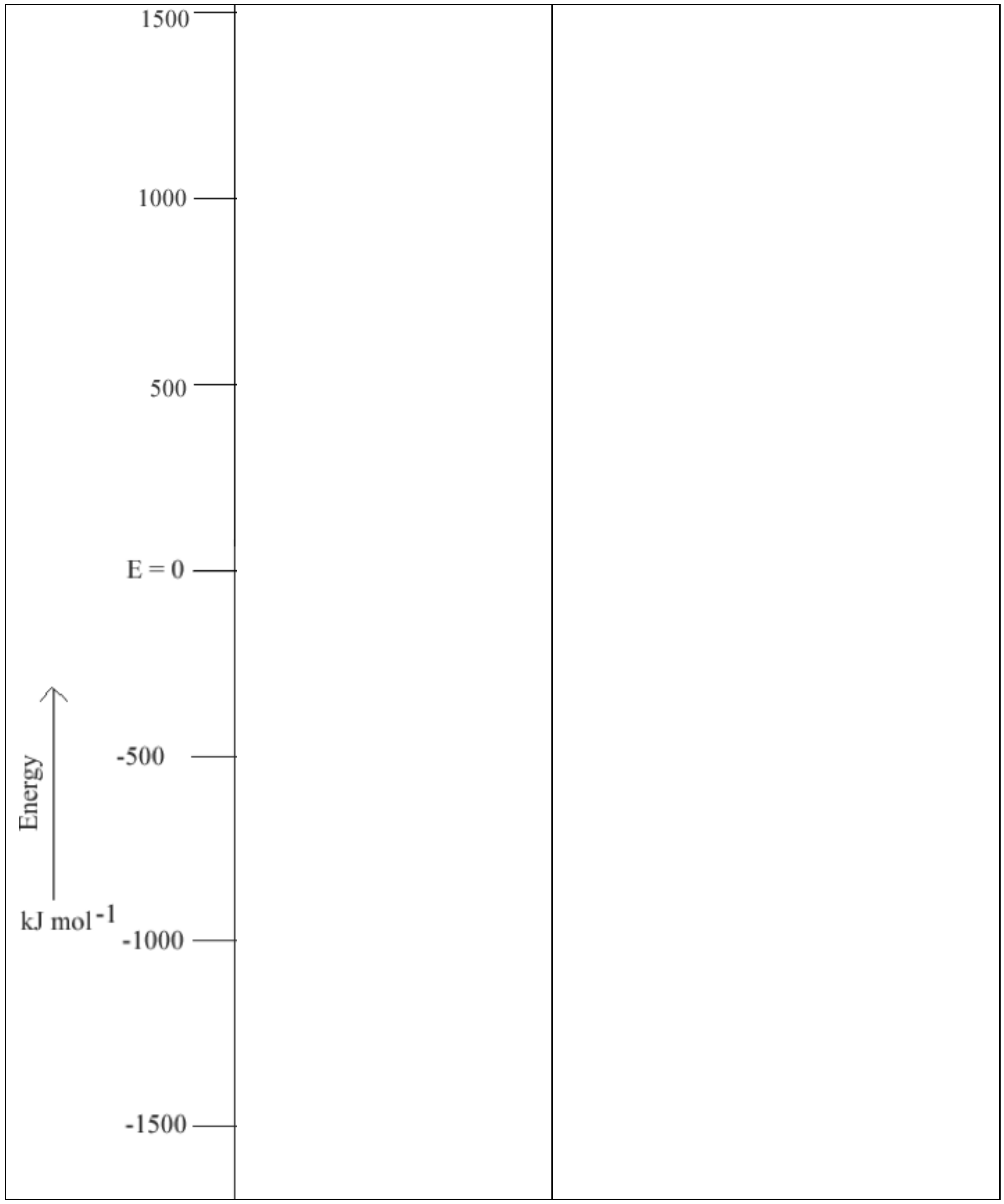


Figure I.

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

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

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

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? How does your explanation account for the relative charge on hydrogen and helium and the distance of the electron(s) from the nucleus. (NOTE: Coulomb's Law is $E \propto \frac{Q_1 \cdot Q_2}{d}$)

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

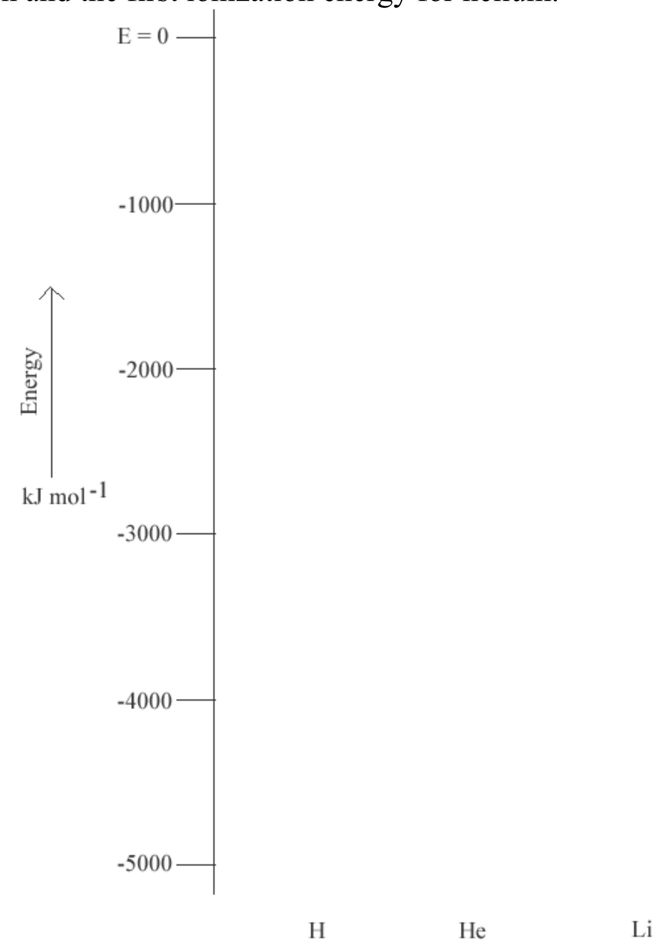


Figure II.

9. How does your diagram illustrate the relative ease with which an electron can be removed from hydrogen and from helium.

10. Predict a value for the first ionization energy for lithium. Do not add your prediction to Figure II. just yet. Justify your prediction based on Question 2.

The value of the first ionization energy of lithium is 520 kJ mol^{-1}. Add this value for lithium to Figure II above. Based on comparisons you made in Question 2 how would you explain the ionization energy for lithium compared to the ionization energy for helium? Compared to hydrogen?

11. 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.

Based on the first ionization energies for hydrogen, helium and lithium that you represented in Figure II. What can you say about the distance of the electrons from their respective nucleus in these three atoms.

12. The first ionization energies for selected elements from the second period of the periodic table follows;

Atom	$_{3}Li$	$_{4}Be$	$_{6}C$	$_{7}N$	$_{9}F$	$_{10}Ne$
Ionization Energy (kJ mol^{-1})	520	899	1086	1302	1681	2081

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

13. The first ionization energy for the element sodium is given in the following table. Predict the other values for the first ionization energy for the selected third period elements;

Atom	$_{11}Na$	$_{12}Mg$	$_{14}Si$	$_{15}P$	$_{17}Cl$	$_{18}Ar$
Ionization Energy (kJ mol^{-1})	495					

How did you arrive at your predictions?

14. Below is a table (Table I) that contains the ionization energy for each of the 18 electrons in an argon atom. The graph of this data is shown in Figure III.

Electron Removed	Ionization Energy (kJ mol^{-1})
1st	-1520.6
2nd	-2665.8
3rd	-3931
4th	-5771
5th	-7238
6th	-8781
7th	-11995
8th	-13842
9th	-40760
10th	-46186
11th	-52002
12th	-59653
13th	-66198
14th	-72918
15th	-82472
16th	-88576
17th	-397604
18th	-427065

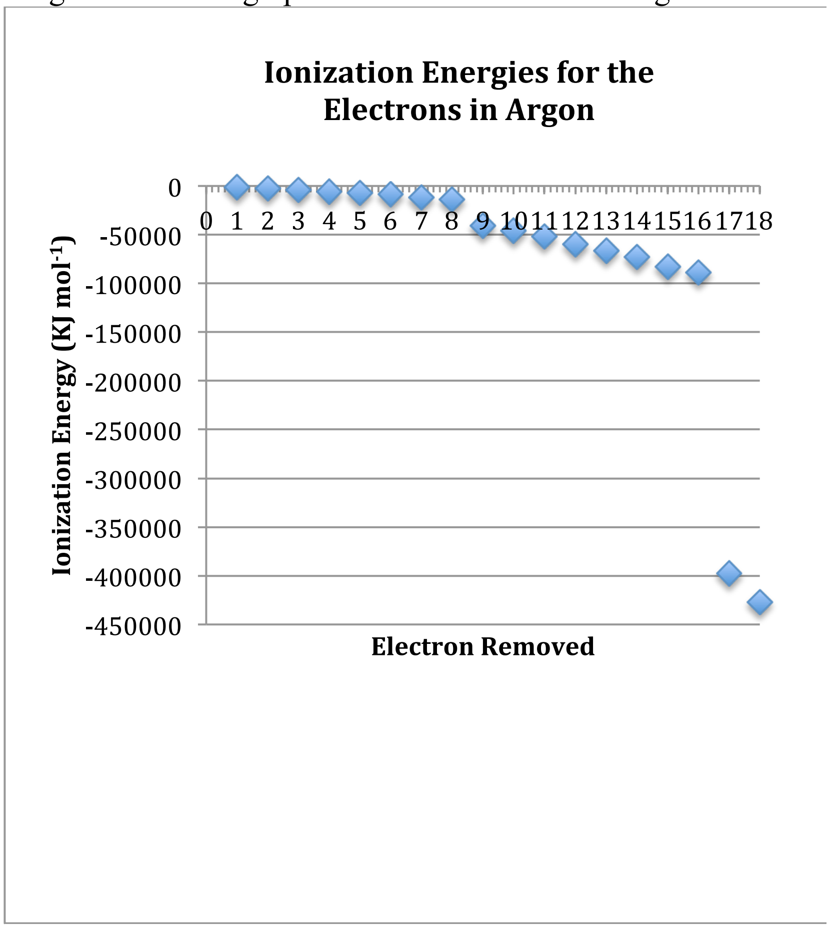


Figure III.

a) Interpret the graph shown in Figure III.

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

c) Indicate the number of electrons in each group/level that you identified?

d) On the graph in Figure IV 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, 3, …. beginning from the lowest energy level. What do these lines represent?

d) How would you describe the relative energy separation of these energy levels?

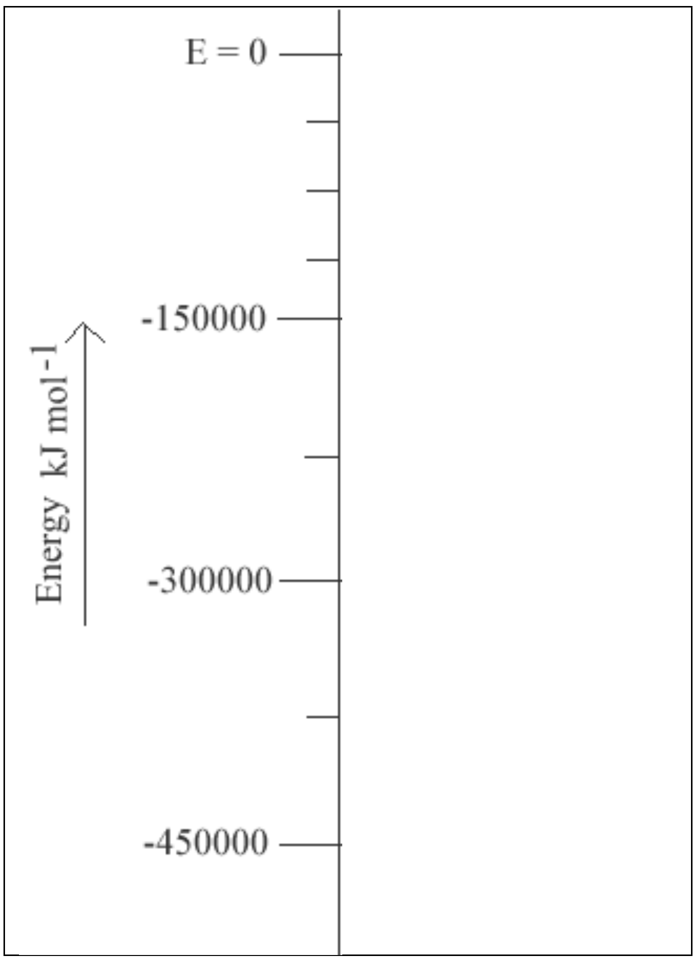


Figure IV

e) An electron from which level requires the least amount of energy to remove? The largest amount of energy to remove?

15. 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.

http://www.webelements.com/argon/atoms.html

Ionization energies for some elements Looked at Argon

NOTES: We could separate this activity into a BCE, DCI and ACA.

Clicker Questions:

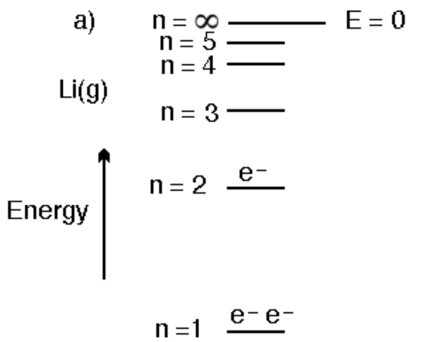
What is the 1st ionization energy for magnesium?
a) 495 kj mol^{-1}
b) 395 kj mol^{-1}
c) 899 kj mol^{-1}
d) 740 kj mol^{-1}
e) 1100 kj mol^{-1}

What is the 1st ionization energy for chlorine?
a) 2100 kj mol^{-1}
b) 1251 kj mol^{-1}
c) 850 kj mol^{-1}
d) 500 kj mol^{-1}
e) 3000 kj mol^{-1}

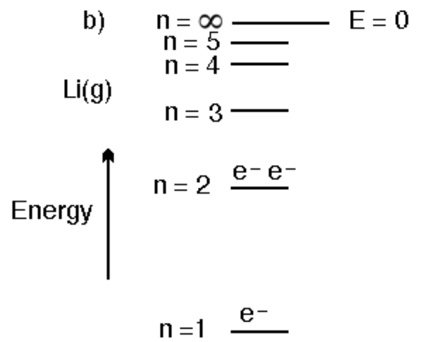
How much energy is required to remove the SECOND electron from a lithium atom?
a) 1300 kj mol^{-1}
b) 2300 kj mol^{-1}
c) 3300 kj mol^{-1}
d) 4300 kj mol^{-1}
e) 5300 kj mol^{-1}

Which of the following best represents the location of the three electrons in the lithium atom

Important note: once it is established that electrons can occupy different shells, we should draw attention to the energy level diagram showing the electrons in shells that are increasing in energy. So as a new shell occurs, the electron is at higher energy so less energy is required to remove the electron. The point is that we do not want to encourage students to use a distance trend to explain the energy trend that we observe. We need to use energy ideas to explain trends in ionization energy.



Energy level digram for Li(g)



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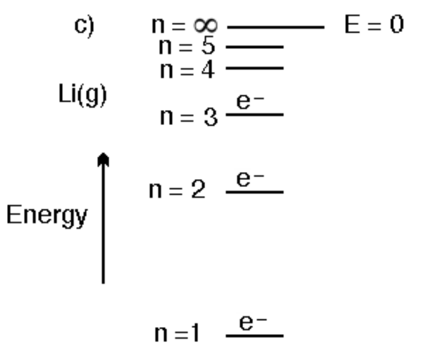

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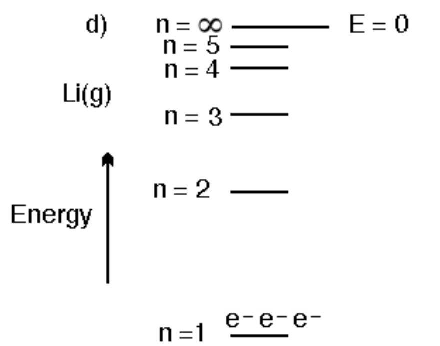
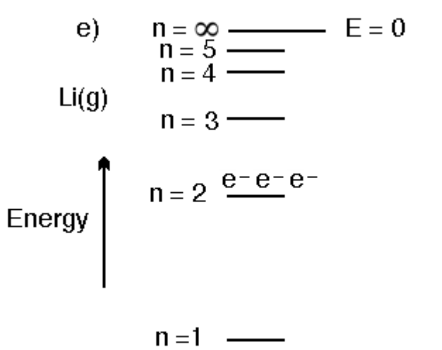


Energy level digram for Li(g)



Energy level digram for Li(g)

For the ACA:

Give energy level diagrams (MC) for beryllium (like we did for lithium), for neon and for sodium.
Predict the first and second ionization energy for sodium and for neon.

Important conclusions:

The shell model has the shells getting further from the nucleus;
Larger size can accommodate more electrons;
As electrons get further from the nucleus less energy is required to remove the electron from the atom;
As electrons are closer to the nucleus it requires more energy to remove the electron;
Going across a period the general trend is for the first ionization energy to increase. For elements with outer electrons in the same shell the ionization energy increases with increasing atomic number (number of protons). However, note there are two exceptions to this explanation;
Going down a group the general trend is for the first ionization energy to decrease because the electron removed is coming from a shell that is further from the nucleus, and therefore requires less energy to remove.

Experimental determination of ionization energies are determined using mass spectrometers. The ionization of the neutral atom is brought about by an electron beam.

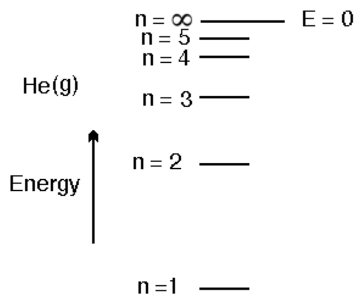
When discussing ionization energy: what electron are you removing.
Rule of thumb: the shell value is the most important factor, number of protons is next, and finally on the number of electrons.

We are not trying to invent Coulomb's law in this activity, we assume students have an idea of what Coulomb's law. In Q2 we are not expecting students to know that charge is more important (term in CL) than distance.

The data say that charge is more important when the electrons are in the same n value.

Comparisons of the type provided in Q2 are the only comparison we see when looking at first ionization energies of elements. We are always comparing the FIE of one atom to another and trying to explain in terms of charge arguments, or in terms of distance arguments why one element's FIE is higher or lower then the other element's FIE.

Note: develop the energy level diagram as we go through the activity. If it takes 1312 kJ of energy to remove an electron from the hydrogen atom that must mean the electron is in a well at -1312 kJ of energy. After inventing shells use spectroscopy data to support transitions between shells, than do PES to add subshells in the energy levels.



Energy level digram for He(g)