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.

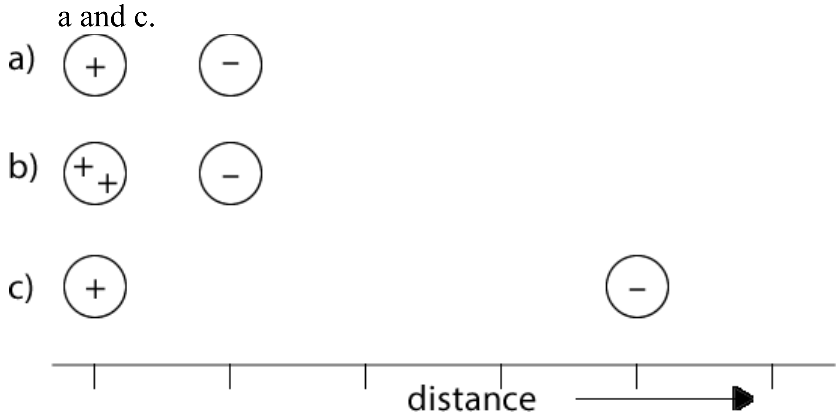
The attraction experienced by the negatively charged electrons to the positively charged nucleus is Coulombic in nature and is described by the equation;

$$\mathbf{E \ \alpha \ \frac{q_1 \cdot q_2}{d}}$$

The equation indicates the energy required to separate the electron (q_1) from the nucleus is directly proportional to the charge on the nucleus (q_2), and inversely proportional to the distance ('d') that separates the electron from the nucleus

NOTE: It is interesting when given the option students will choose to use those words that they feel they understand. So some of the words in the list may not appear and under those circumstances we might assume the student does not really have a good understanding of the term.

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.

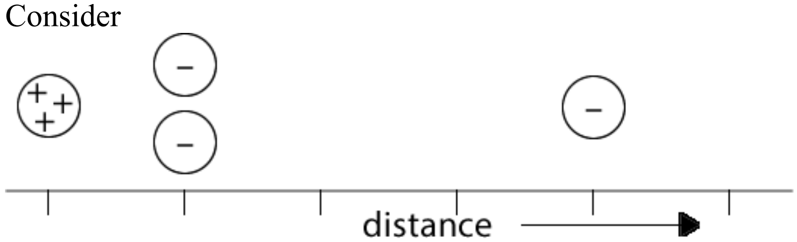


NOTE: The negative charge is the same distance from the positive charge in both a) and b), so the distance term in Coulomb's Law (E α $\frac{q_1 \cdot q_2}{d}$) is the same for both. However, the positive charge is greater in b) compared to a). The energy required to separate the negative charge from the positive charge in b) is greater

than the energy required to separate the negative charge from the positive charge in a).

NOTE: The negative charge is at a different distance from the positive charge in both a) and c), so the distance term in Coulomb's Law (E α $\frac{q_1 \cdot q_2}{d}$) is important. The positive charge in a) and c) are the same. The energy required to separate the negative charge from the positive charge in a) is greater than the energy required to separate the negative charge from the positive charge in c).

3. Consider



a) how many electrons do you see in the picture? **3 electrons** How many protons? **3 protons**

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

The electron furthest to the right (furthest from the nucleus) will be the easiest to remove.

c) Explain your response in b.

According to Coulomb's Law (E α $\frac{q_1 \cdot q_2}{d}$) the energy of attraction (required for separation) is inversely proportional to the distance the electron is from the nucleus.

d) compare the energy from 3b with the energy in 2a and then in 2c.

When comparing 3b to 2a we can think the following way; the electron that is furthest from the nucleus in 3b only experiences an attraction of a net positive charge of +1 because the two electrons in the inner core shield two of the three positive charges in the nucleus from the outer most electron. So the electron in 3b is further from a net +1 positive charge compared to the electron in 3a, which is also experiencing a net +1 charge on its nucleus. Therefore the energy required to remove the electron in 3b is smaller compared to the energy required to remove the electron in 2a.

When comparing 3b to 2c the electron that requires the least amount of energy to remove is approximately the same distance from the nucleus. Also notice

that while the nuclear charge in 3b greater, there are also two electrons that 'shield' some of that nuclear charge from the electron the furthest from the nucleus. The net result is the energy required to remove the electron that is the furthest from the nucleus in 2c and 3b is about the same.

Useful Questions:

What are the similarities and difference between the images in 2a and 2b?
Which (2a or 2b) requires more energy to remove the electron?
Why is less energy required to remove the electron in 2b compared to 2a?
Why is more energy required to remove the electron in 2a compared to 2b?

What are the similarities and difference between the images in 2a and 2c?
Which (2a or 2c) requires more energy to remove the electron?
Why is less energy required to remove the electron in 2c compared to 2a?
Why is more energy required to remove the electron in 2a compared to 2c?
It is VERY important that students always mention both charge and distance in their explanations. This is critical, so even though the distance is the same in 2a and 2b they must point that out in their argument. Just as they must mention that the nuclear charge is the same in 2a and 2c in their argument. Students must know that stating the obvious is most often important in identifying data to support a claim.

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;

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

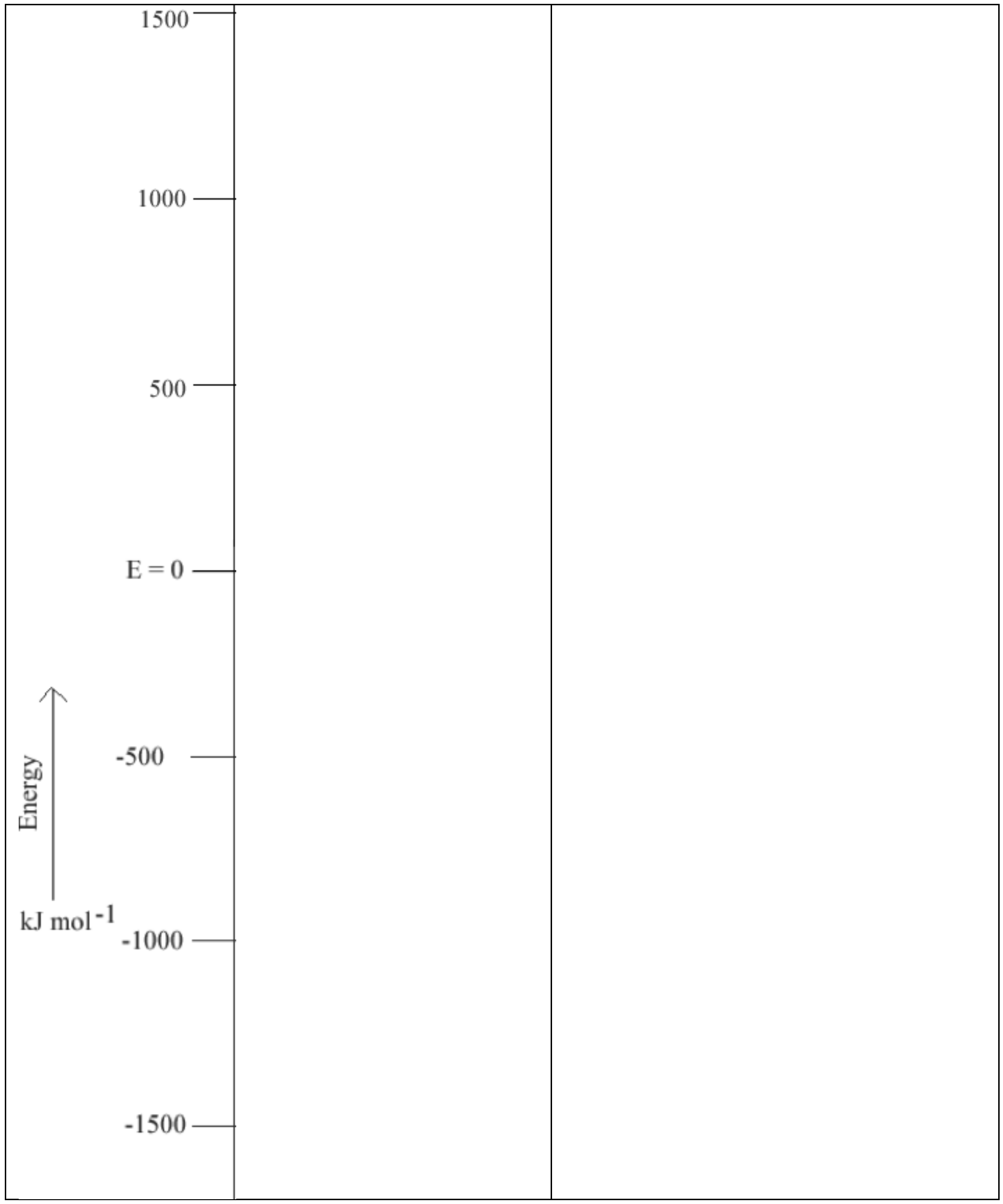
4. In the ionization equation above, which is at lower energy? A(g) or $A^{+}(g)$ and $1e^{-}$? Which is at higher energy? A(g) or $A^{+}(g)$ and $1e^{-}$? Explain.

A(g) is at lower energy since according to the equation energy must be added to A(g) to remove the electron. $A^{+}(g)$ and $1e^{-}$ is higher in energy.

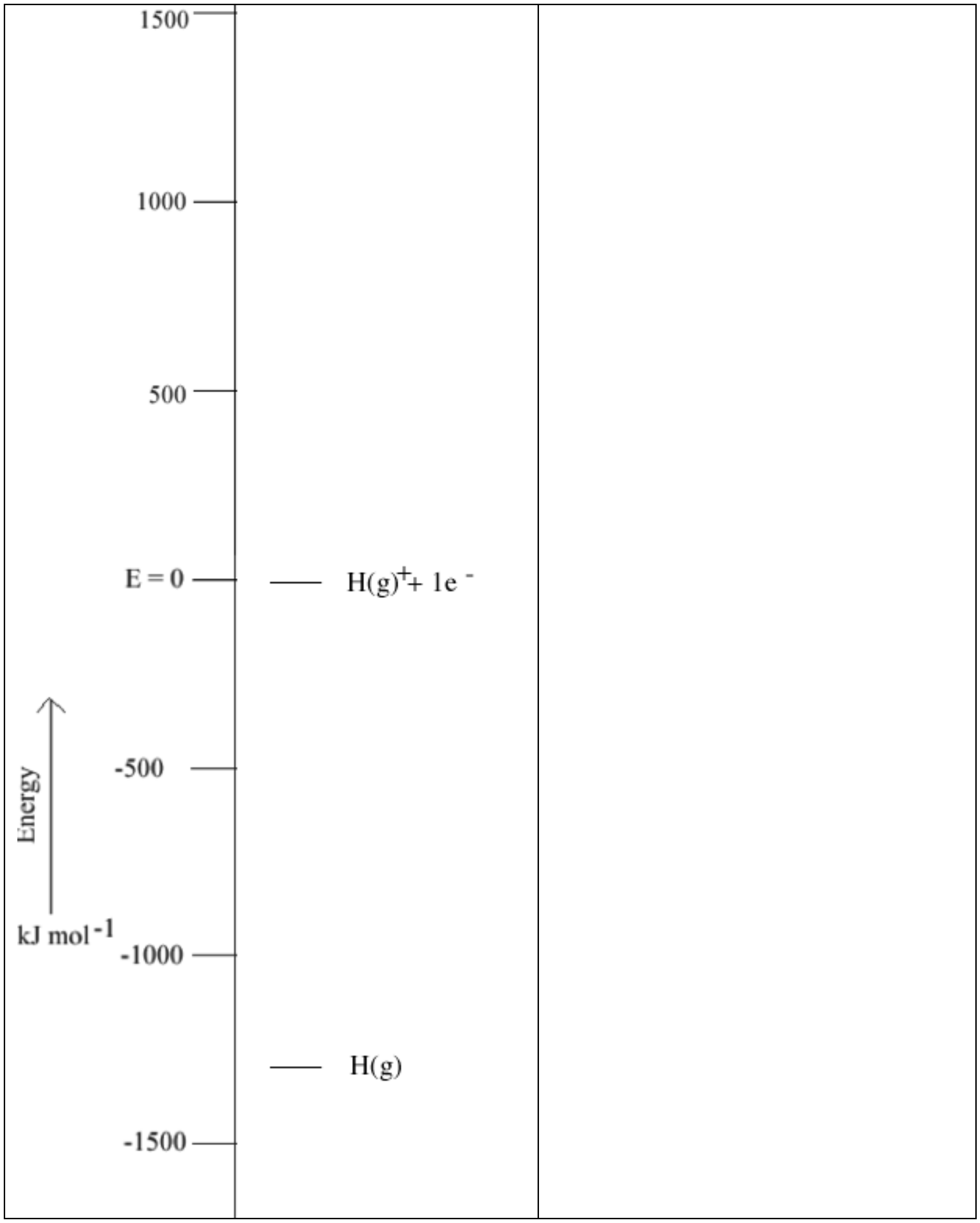
5. Explain why energy is required (an endothermic process) to remove the electron in a neutral atom.

Since opposite charges are attractive in nature energy is required to separate oppositely charge particles.

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.)



This is a critical point in the discussion. Students know the line for the energy of H(g) and the line for energy for H^+(g) + 1e^- are 1312 kJ mol^{-1} apart, but they do not know where on the y-axis to draw each line. We only know the energy that separates the two lines. To arrive at where the lines are drawn I explain to the students that when the electron is completely removed from the nucleus we will define that as a system of zero energy. When the electron is an infinite distance from the nucleus that that situation is zero energy. Now as the electron moves closer and closer to the nucleus at some point there is an attraction between the electron and the nucleus. The attraction results in a lower energy system, so the line for the H(g) is at -1312 kJ mol^{-1}.



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

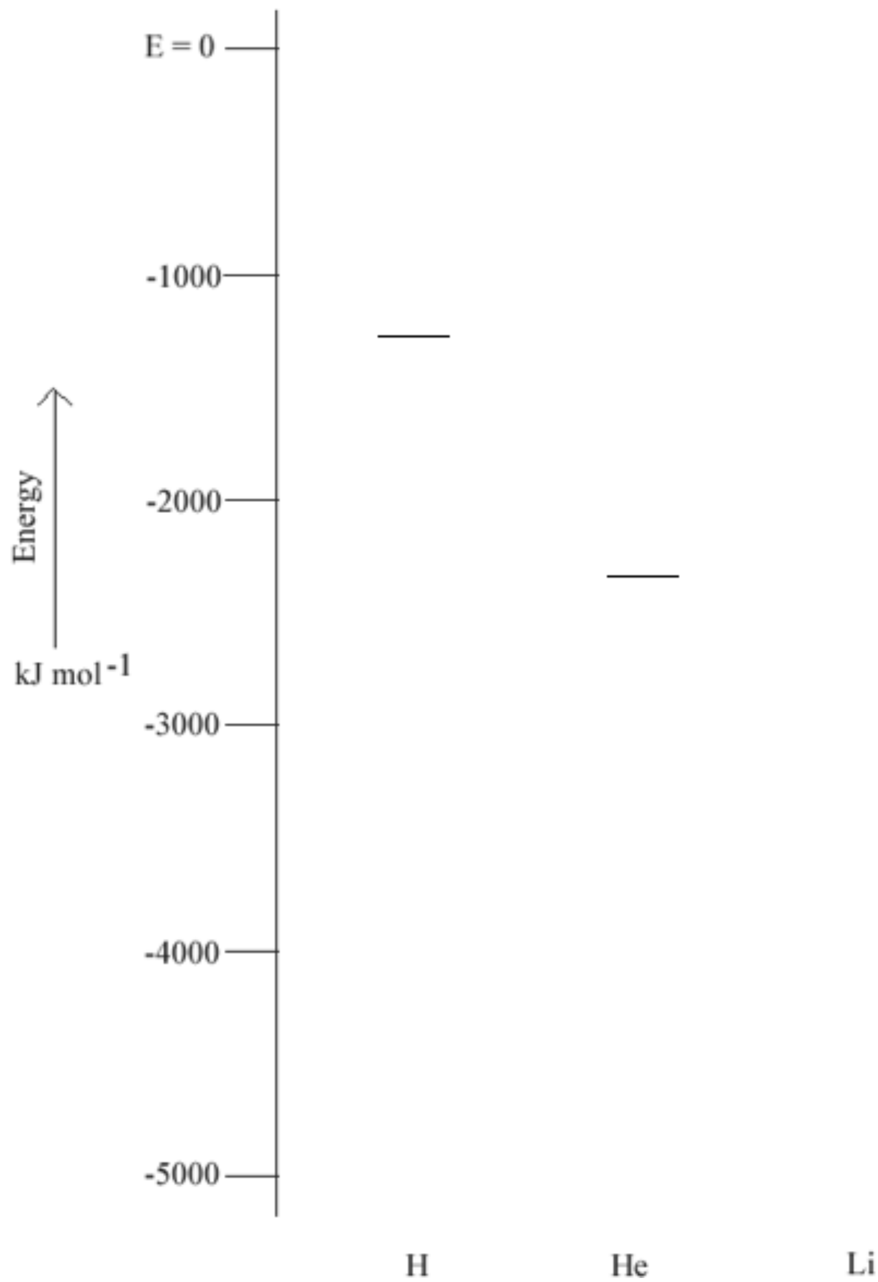
The energy difference represents the ionization energy for the hydrogen atom in the gas phase.

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.



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

Comparing the first ionization energy of helium to hydrogen follows very closely the model depicted in 2a and 2b. For hydrogen the single electron experiences an attraction to a single proton in its nucleus. For helium the two electrons experience an attraction to a nucleus with two protons. Since the first ionization energy for helium is nearly twice the first ionization energy for hydrogen it is reasonable to assume that the two electrons in helium are about the same distance from the nucleus as the one electron in hydrogen. If the electrons in helium were at different distances from the nucleus we would expect the first ionization energy to be much smaller compared to the first ionization energy in hydrogen. Since the electron that is closer to the helium nucleus would shield some of the nuclear charge from the outer electron, which would be further from the nucleus. The experimental data does not support that model.

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.

Two possible predictions: 1) assuming the electron is the same distance from the nucleus as the first two electrons we might predict a value approximately 3 times that of hydrogen or 1.5 times that of helium; or 2) that the new electron is further from the nucleus than the first two in which case the ionization energy would be considerably less that that of helium. We would expect less since if the electron is further, the two inner electrons would partially shield some of the positive charge on the nucleus in lithium.

Questions:

On what basis (model…Q2) did you make your prediction? Note: whenever the student makes a prediction they must articulate the distance the electron is from the nucleus.

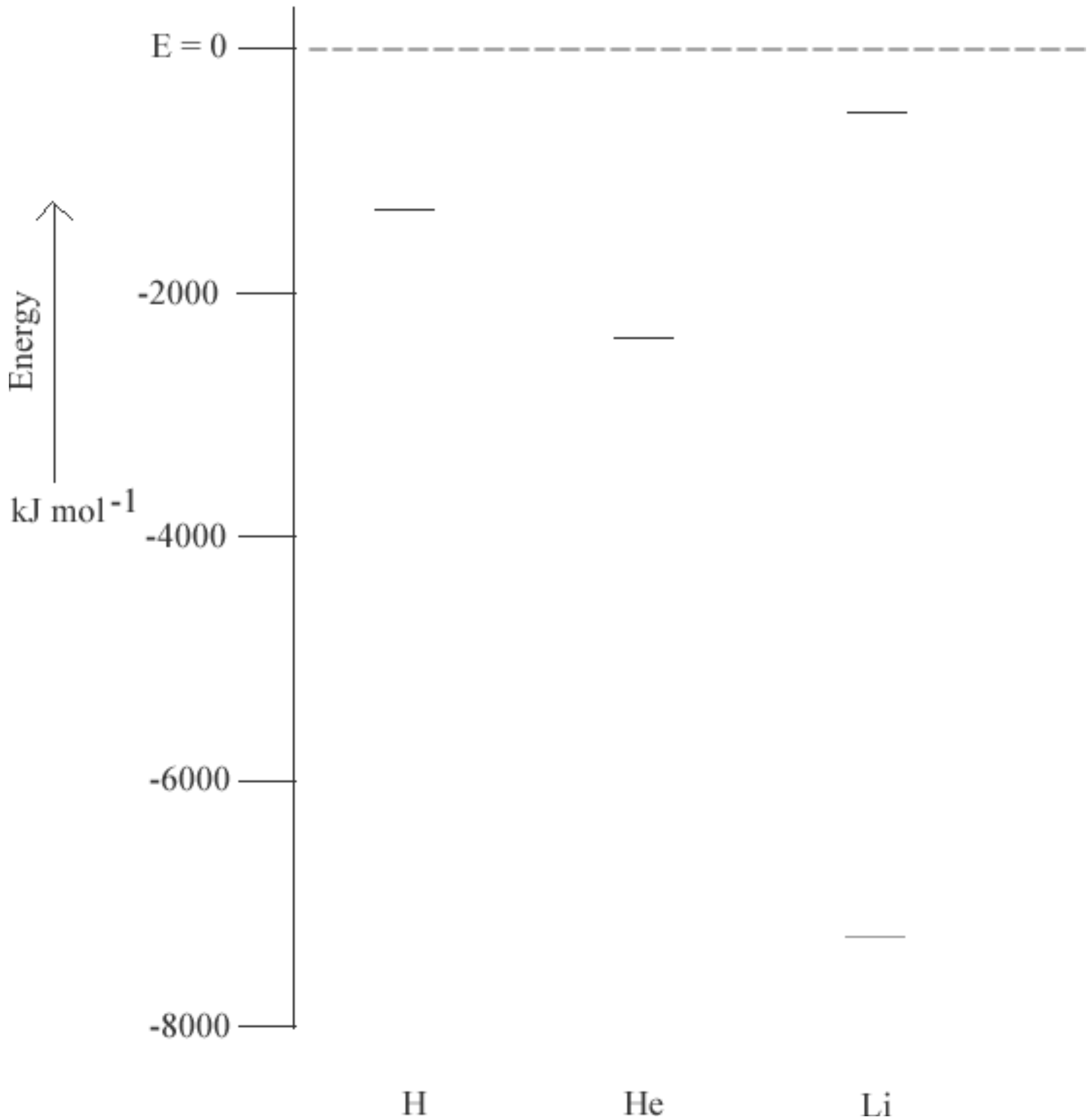
11. The value of the ionization energy of lithium is 520 kJ mol^{-1}. Based on comparisons you made in Q2 how would you explain the ionization energy for lithium compared to the ionization energy for helium? Compared to hydrogen?

Since the first ionization for lithium is smaller than either of the first ionization energies for hydrogen or helium, it would indicate that the easiest electron to be removed from lithium is at a greater distance from the nucleus compared to the electron ionized from hydrogen or helium.

12. 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.

The predicted energy required to remove a second electron from lithium would be 3 times greater than the energy required to remove an electron from hydrogen. Since the lithium nucleus has three protons, it would require about three time the energy. This assumes the two electrons in lithium are about the same distance from the nucleus as the electron in hydrogen and the two electrons in helium.

Use the energy level diagram below locate the three electrons in lithium and label the energy (E =) on the diagram required to remove one of the electrons.


E = 0
-2000
-4000
-6000
-8000
Energy
kJ mol-1
H
He
Li

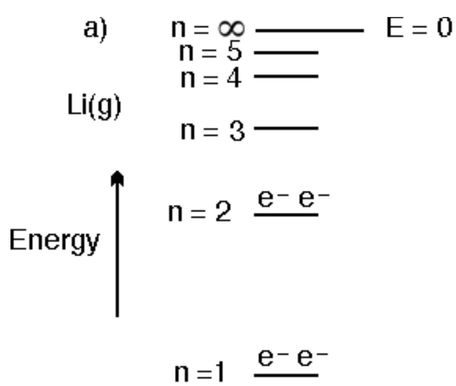
13. The first ionization energies for selected elements from the second period of the periodic table follows;

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.

Looking at the first ionization energies for the elements lithium through neon it is evident that there is an increase as we proceed from lithium to neon. Also, looking at the atomic number (the subscripted number to the left of the element symbol) there is an increase in the number of protons proceeding from lithium to neon. Since we see an increase in the ionization energy with an increase in the number of protons in the nucleus we can assume that the electron that is removed from each of these elements must be approximately the same distance from the nucleus. If this were not the case we would expect to see a decrease in the first ionization energy at some point.

For beryllium use the energy level diagram below to locate its four electrons and label the energy (E =) on the diagram required to remove one of the electrons.



Energy level digram for Be(g)

14. The first ionization energy for the element sodium is given in the following table. Predict the other values 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	700	900	1100	1450	1700

How did you arrive at your predictions?

It is reasonable to assume the same behavior in the third period elements as was observed in the second period elements. So the first ionization energy should increase going across the period. However, since the electrons in this period are further away from the nucleus one can assume they are each less than the first ionization energy for the corresponding element in the second period. When predicting the first ionization of these elements each new first ionization energy in the period must be higher than the first ionization energy for the preceding element, and smaller than the first ionization energy for the element in the group just above.

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.

Based on the experimental evidence from the first ionization energies it appears that electrons in atoms occupy shells. The electrons in the first shell must be at the lowest energy because of all of the first ionization energies, the electrons in the first shell require the most energy to remove. Also based on the first ionization energies it appears that the first shell holds a total of 2 electrons. The second shell holds eight electrons. The third shell holds 18 electrons, although experimental evidence is not presented in this activity that would lead one to that knowledge. We can understand this model using Coulomb's Law which helps explain the experimental data of the first ionization energies going across a period from left to right, and down a group from top to bottom. Electrons in the different shellsProtons in the nucleus

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}

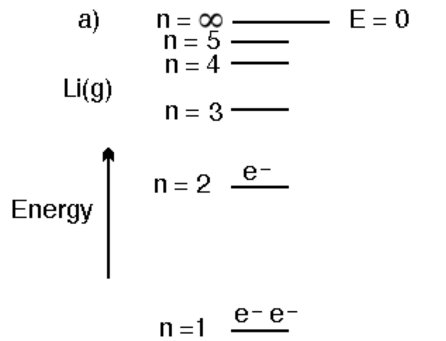
What is the 1st ionization energy for chlorine?
a) 2100 kj mol^{-1}
b) 1251 kj mol^{-1}
c) 850 kj mol^{-1}
d) 500 kj mol^{-1}
e) 3000 kj mol^{-1}

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

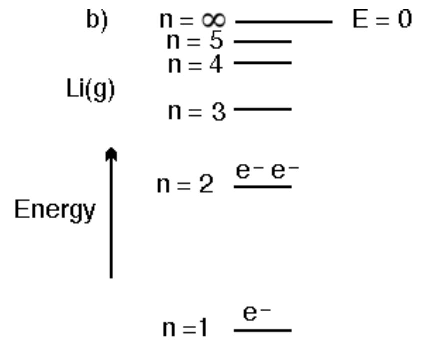
Important note: once it is established that electrons can occupy different shells, we should draw attention to the energy level diagram showing the electrons in shells that are increasing in energy. So as a new shell occurs, the electron is at higher energy so less energy is required to remove the electron. 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.

a)



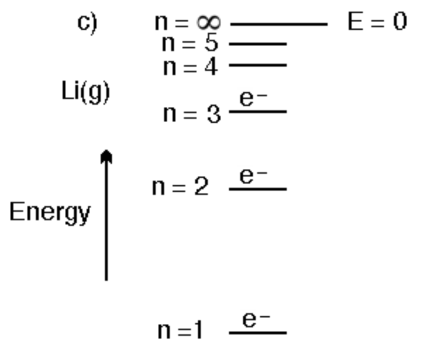
Energy level digram for Li(g)

b)



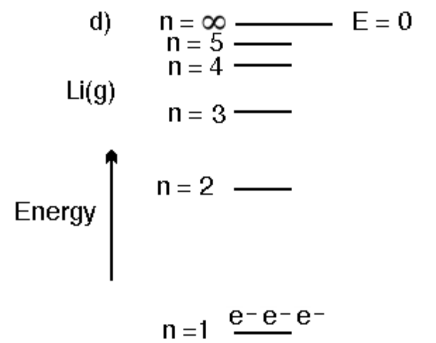
Energy level digram for Li(g)

c)



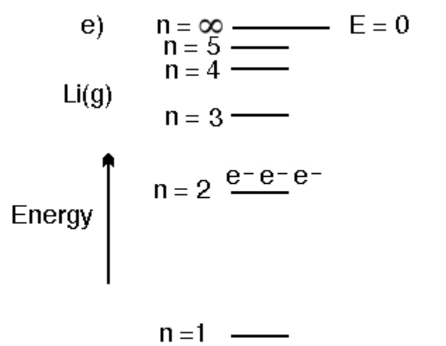
Energy level digram for Li(g)

d)



Energy level digram for Li(g)

e)



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.