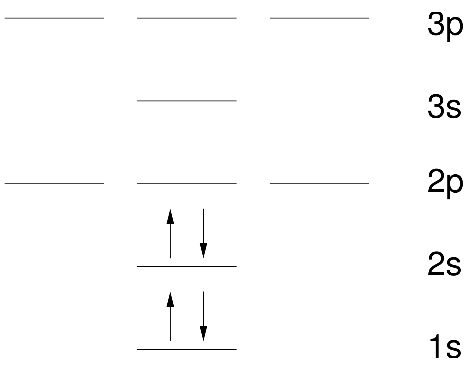
# Physics 008—Tutorial 6: The Periodic Table

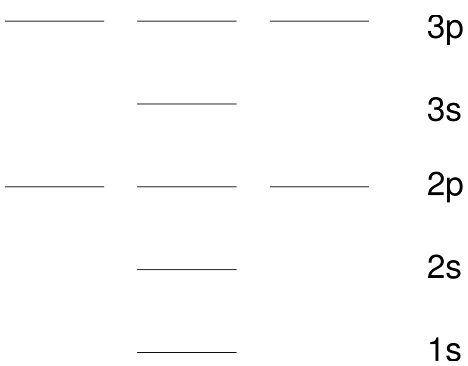
## 1. Second-period elements

In class, we discussed how to represent the electron configurations of Hydrogen, Helium, and Lithium. In the tutorial, you will extend that analysis to more complicated elements.

Let's begin with Beryllium which has four electrons. Using the Pauli principle, we begin filling the lowest electron wavefunctions. The 1s wavefunction can hold both a spin up and a spin down electron as can the 2s. So the configuration looks like:



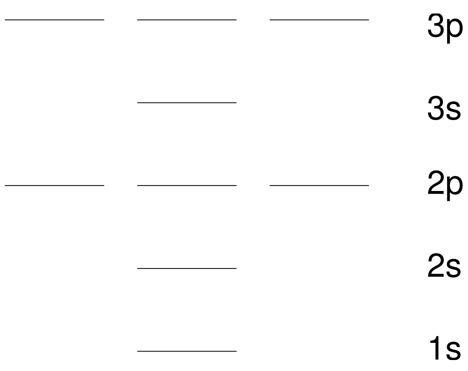

The next element is Boron which has five electrons. What is the configuration of electrons in the ground state (or lowest energy state) of Boron?




A student, Marge, notes that is doesn't matter which of the three 2p wavefunctions ($p_x$, $p_y$, or $p_z$) is used for the fifth electron because all have the same energy and hence are equally likely to be occupied.

Do you agree with Marge?

Now we come to Carbon. What is the lowest-energy configuration for the six electrons in a Carbon atom? The first four electrons look just like the Beryllium atom, but where should we put the next two electrons? Do they go in the same 2p wavefunction, or into different ones?

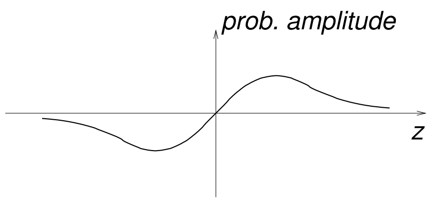



Another student, Homer, argues that the reasoning Marge used for Boron also applies here: it doesn't matter which combination of 2p wavefunctions we choose because they all yield the same energy.

Do you agree with Homer?

Let's consider this question more carefully. We will proceed in the simplest possible fashion, avoiding the use of complicated mathematics. But, like our 'spherical cow' model for the atom, this analysis contains the essential ideas.

Suppose the first electron occupies the $p_z$ wavefunction. This graph shows what the $p_z$ wavefunction looks like.




- What is the probability that the first electron will be found at the origin?

- Indicate on the graph the location(s) where the electron is most likely to be found. Explain how you can tell.

Let us simplify things by assuming that the electron in the $p_z$ wavefunction spends half of the time at location $z = a$ and half of the time at location $z = -a$, where $a$ and $-a$ are the locations of the maximum and minimum in the wavefunction plotted above.

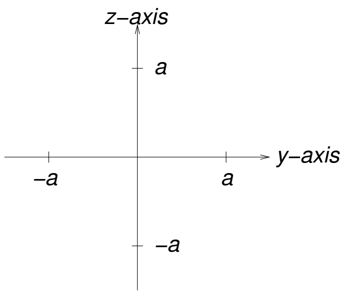
- Explain why this simplification is just an approximation.

Now suppose a second electron also has the $p_z$ wavefunction, and spends half the time at $z = a$ and half the time at $z = -a$. Determine the probability...

- that both electrons are at $z = a$.
- that both electrons are at $z = -a$.
- that one is at $z = a$ and the other is at $z = -a$.
- Check to make sure that the sum of these probabilities makes sense.

Use your results above to determine the average separation between two electrons if both have the $p_z$ wavefunction.

Now suppose the second electron has a different p wavefunction, say $p_y$. Is the average separation between the two electrons greater than, less than, or the same as the average separation when both have the same wavefunction? (The picture shown below may be helpful.) Explain your reasoning.




In light of this, is there any reason why certain choices for how two electrons occupy 2p wavefunctions might be preferable to other choices? (*Hint*: Do electrons like to be close to each other?) Explain.

Complete the electron configuration for Carbon, making sure your answer is consistent with the arguments made above.

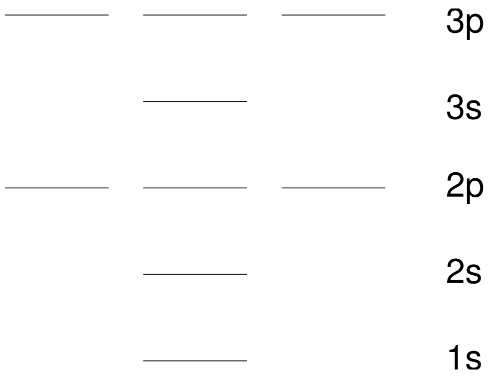
There is a general rule for dealing with how to choose wavefunctions and spins when there appear to be multiple possibilities with the same energy. This rule, called **Hund's rule**, states that in such a situation you should choose a configuration in which the spins are aligned in the same direction as much as possible.

- Discuss the relationship between Hund's rule, the Pauli exclusion principle, and the fact that electrons are electrically charged.

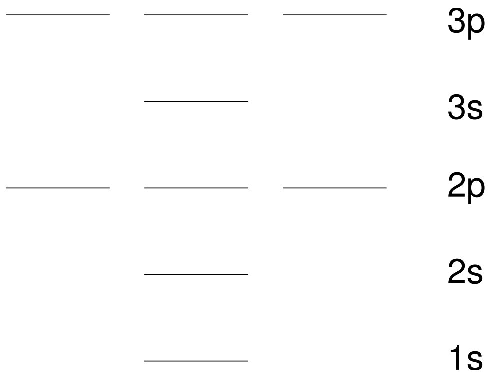
- Check that your answer for the configuration of electrons in Carbon is consistent with Hund's rule.

Now complete the configurations for the rest of the second period elements: Nitrogen, Oxygen, Fluorine, and Neon.

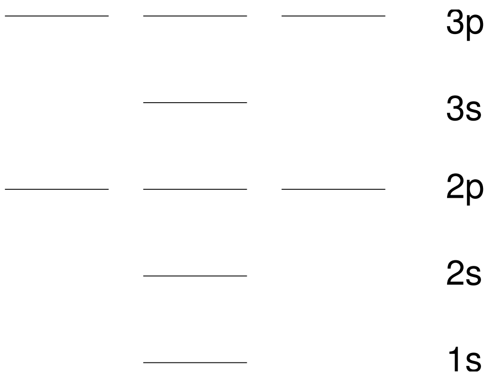
Nitrogen



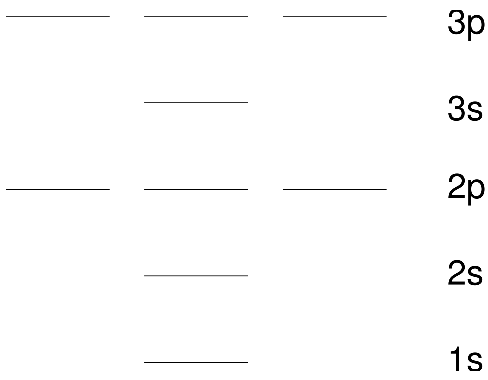

Oxygen




Fluorine




Neon



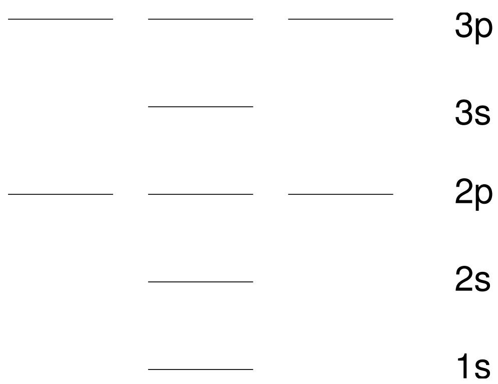

**Check your results with an instructor before proceeding to the next section.**

## 2. Third-period elements

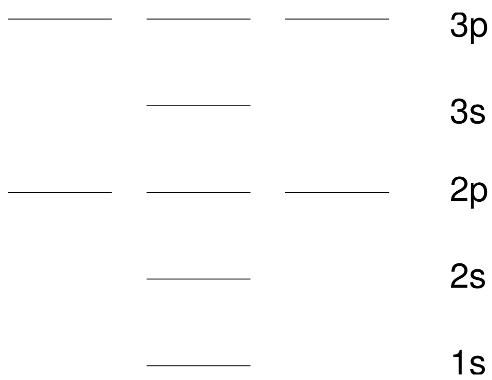
For the third period elements, the electrons are filled in the same order as before 1s, 2s, 2p, 3s, and 3p.

Using the diagrams below fill in the electrons for Magnesium, Phosphorus, and Argon.

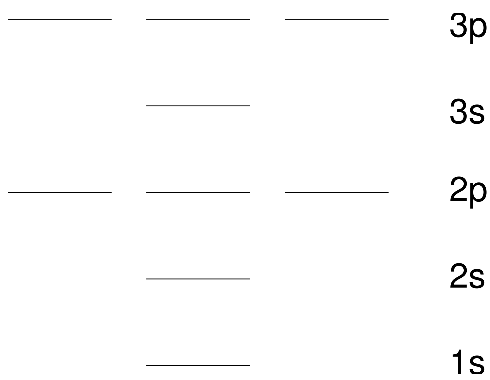
Magnesium




Phosphorus




Argon



## 3. Discussion

In the mid 1800's, Mendeleev discovered that properties of the elements repeat periodically as the mass of the elements increases. He used that observation to predict new elements that had not yet been found, and was even able to predict some of the basic properties of those elements.

It wasn't until Pauli came around with the Pauli exclusion principle in the 1920's that this repeating or periodic behavior was explained.

The reason why certain elements have similar properties is that the closed shells of electrons act almost as if they aren't even there. It is primarily the outer shell electrons that determine the chemical properties of an element.

Consider the third-period elements examined in the previous section: Magnesium, Phosporus, and Argon. In each case, identify the corresponding second-period element that has similar properties.

## 4. Fourth-period elements

The fourth-period elements fill the d wavefunctions as well as the s and p wavefunctions. The ordering of energy levels is: 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p.

Calcium, with 2 electrons in the 4s level, which is the highest occupied level, is an element similar to Magnesium and Beryllium. Scandium is the next element in the periodic table, and it contains one electron in the 3d shell. Which fourth-period element is most similar to Carbon? Draw the electron configuration diagram for this element.