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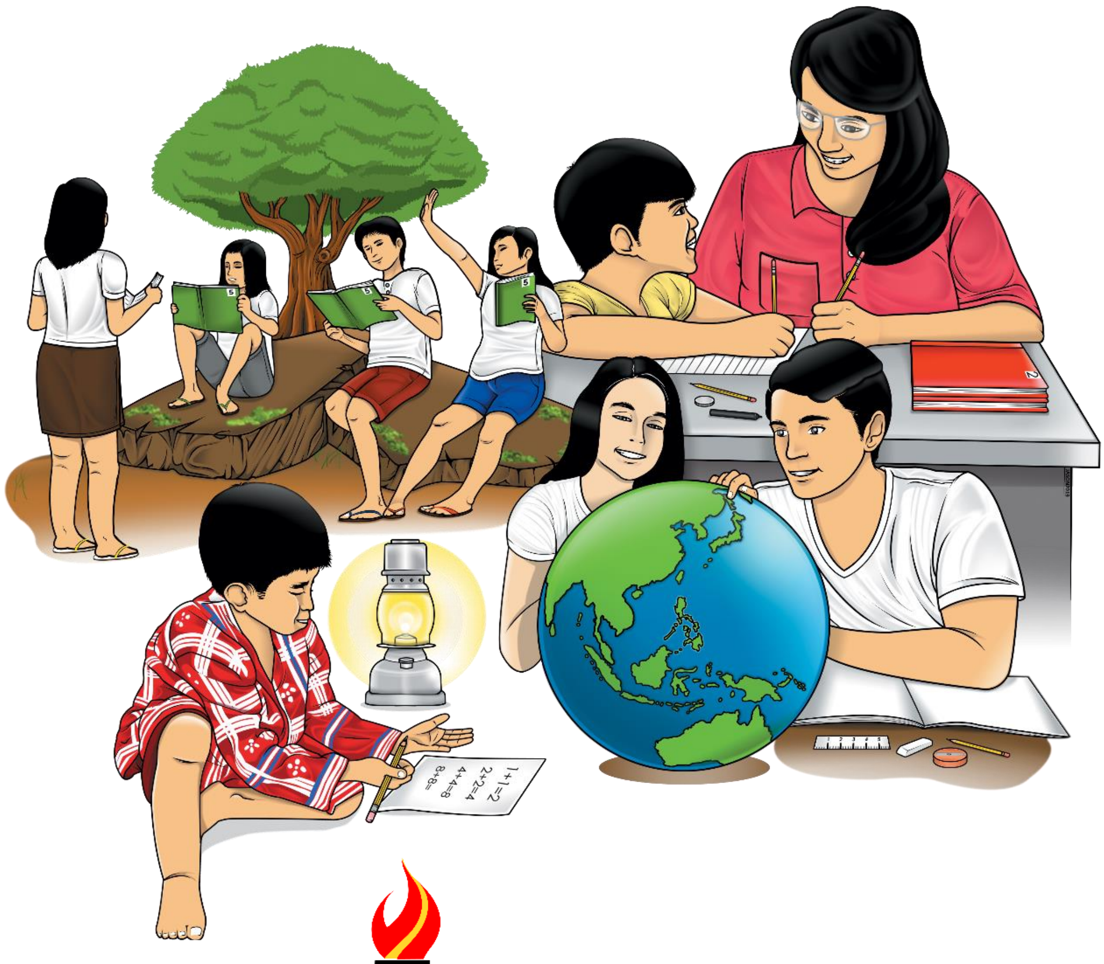
Science

Quarter 2 – Module 1:
Quantum Mechanical Model of an Atom



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Development Team of the Module

Author/s:	Vida May M. Mohamad, Perlita B. Yee
Reviewers:	
Illustrator and Layout Artist:	Donnie Ray E. Obina
Management Team:	Roy Angelo E. Gazo
	Nimfa R. Lago
	Mala Epra B. Magnaong
	Henry B. Abueva
	Ann Q. Solijon
	Sherlita L. Daguisonan
	Meriam S. Otarra
	Charlotte D. Quidlat

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Department of Education – Regional Office 10

Office Address: Zone 1, Upper Bulalang, Cagayan de Oro City 9000
Telefax: (088) 880-7072
E-mail Address: region10@deped.gov.ph

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Science

Quarter 2 – Module 1:
Quantum Mechanical Model of an Atom

DEPARTMENT OF EDUCATION

Introductory Message

This Self-Learning Module (SLM) is prepared so that you, our dear learners, can continue your studies and learn while at home. Activities, questions, directions, exercises, and discussions are carefully stated for you to understand each lesson.

Each SLM is composed of different parts. Each part shall guide you step-by-step as you discover and understand the lesson prepared for you.

Pre-tests are provided to measure your prior knowledge on lessons in each SLM. This will tell you if you need to proceed on completing this module or if you need to ask your facilitator or your teacher's assistance for better understanding of the lesson. At the end of each module, you need to answer the post-test to self-check your learning. Answer keys are provided for each activity and test. We trust that you will be honest in using these.

In addition to the material in the main text, Notes to the Teacher are also provided to our facilitators and parents for strategies and reminders on how they can best help you on your home-based learning.

Please use this module with care. Do not put unnecessary marks on any part of this SLM. Use a separate sheet of paper in answering the exercises and tests. And read the instructions carefully before performing each task.

If you have any questions in using this SLM or any difficulty in answering the tasks in this module, do not hesitate to consult your teacher or facilitator.

Thank you.

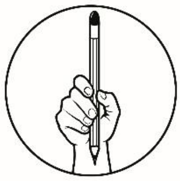
What I Need to Know

In previous grade, you learned about Rutherford's atomic theory. According to this theory, an atom is mostly empty space and its mass is concentrated in a small region at the center called nucleus. The protons and neutrons are located inside the nucleus while the electrons are distributed around the nucleus. However, this model could not explain the characteristic color of flame emitted by metals when heated.

In this module, you will learn about Niels Bohr's atomic model. Furthermore, you will gain an understanding about the quantum mechanical model of the atom. This is important so you will understand that the characteristics of matter are related to how electrons are distributed inside the atoms.

The lessons in this module are aligned on the learning competency:

- Explain how the Quantum Mechanical Model of the atom describes the energies and positions of the electrons.



What I Know

Multiple Choice: Select the letter of the best answer from among the given choices. Write it on a separate sheet of paper.

1. What does the flame test prove about the inner structure of atom?
   A. The atom has a nucleus.
   B. The nucleus is positively charged.
   C. The electrons are found outside the nucleus.
   D. The electrons carry discreet or fixed energy.
2. What happens to the energy of an electron as it goes farther from the nucleus?
   A. Its energy increases.
   B. Its energy decreases.
   C. Its energy becomes fixed.
   D. Its energy does not change.
3. Copper chloride when heated emits blue light. What is the origin of this blue light?
   A. The nucleus radiates energy.
   B. The electron loses energy as it moves around the nucleus.
   C. The electron absorbs energy as it jumps to a higher energy level.
   D. An excited electron loses energy as it returns to a lower energy level.
4. Which of the following energy levels can accommodate a maximum of 18 electrons?
   A. 1^{st} energy level
   B. 2^{nd} energy level
   C. 3^{rd} energy level
   D. 4^{th} energy level
5. An atom with 32 electrons has ______ energy levels.
   A. 2 B. 2 C. 3 D. 4
6. How many sublevels are in L energy level?
   A. 1 B. 2 C. 3 D. 4
7. How many atomic orbitals are in p sublevel?
   A. 1 B. 2 C. 3 D. 4
8. How many electrons can the d orbital holds?
   A. 2 B. 6 C. 10 D. 14
9. Which of the given atomic orbitals is of higher energy?
   A. 1s B. 2s C. 2p D. 3p
10. Which is the electron configuration of Oxygen ($8e^-$)?
    A. $1s^22s^22p^6$ B. $1s^22s^22p^4$ C. $1s^22s^32p^3$ D. $1s^12s^22p^3$

Lesson 1 Electrons and Energy Level

What I Need to Know

At the end of the lesson, you will be able to:

1. relate colors of light emitted by metals to the structure of the atom.
2. infer that electrons can stay only in definite energy levels
3. identify the energy levels, sublevels, and atomic orbitals in an atom
4. determine the maximum number of electrons that can stay in an energy level

What's New

Photo illustrated by: Donnie Ray Obina

Striking display of fireworks is done all over the world during New Year's Eve. Have you observed the different colors of light emitted by these fireworks? Do you know what is responsible for this array of colors? Would you believe that this is due to the arrangement of electrons within the atoms? Excited to discover more about the atom? Let's go…

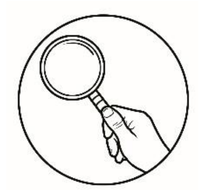
Firework effects are produced by the combustion of explosive materials present in fireworks. These explosive materials are also called metal salts. Metal salts emit characteristic color of light when heated as shown in the Table 1.

Table 1. Color emitted of some metal salts and its element responsible for its color

Metal salts	**Element giving color**	**Color of flame**
Sodium Nitrate ($NaNO_3$)	Sodium (Na)	Yellow
Barium Chloride ($BaCl_2$)	Barium (Ba)	green
Barium Nitrate (Na_2NO_3)	Barium (Ba)	green
Calcium Chloride (Ca_2Cl)	Calcium (Ca)	Orange
Copper Chloride (CuCl)	Copper (Cu)	Blue
Lithium Carbonate (Li_2CO_3)	Lithium (Li)	red

Analyze the information given in the table 1 and answer Q1 and Q2.

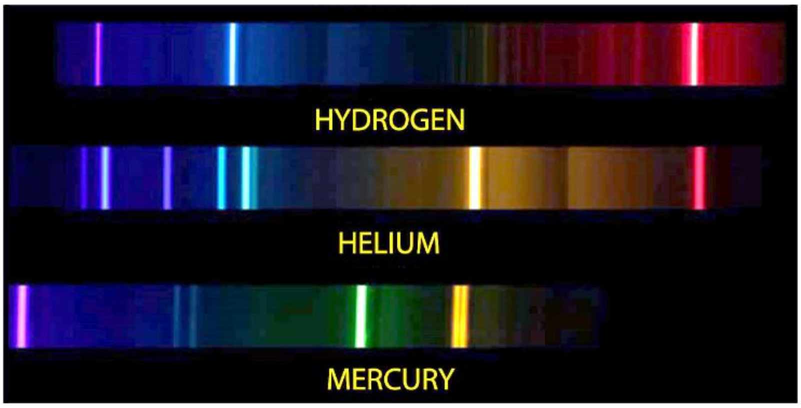
Q1. What can you conclude about the elements and the color of flame produced?
Q2. If sodium nitrate is change to another salt of sodium, ex. Sodium chloride (table salt), do you think the color of the flame would be the same or different? Why?



What is It

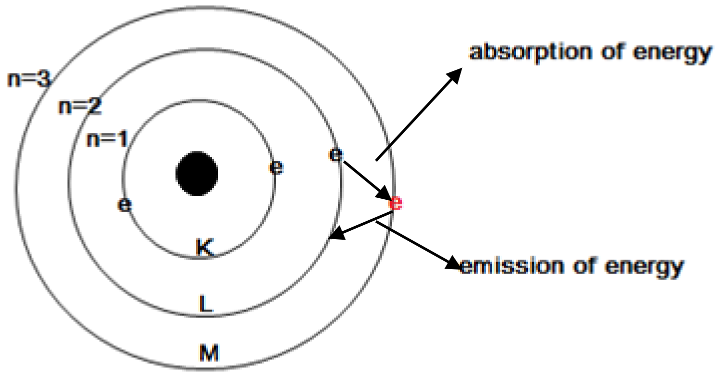
Each color of light has a specific wavelength. Among the visible light, red light has the longest wavelength and has the lowest energy. Violet light has the shortest wavelength and has the highest energy.

When compounds of different elements are heated over a flame, it comes to a point where the hot gaseous atom begins to emit light of a definite color. Analysis of light given off by the vapors of elements can be done more precisely with an instrument called spectroscope. With the use of spectroscope, one can detect a series of narrow lines or line spectrum on the light given off by an element. The spectral lines suggest different energy levels in an atom.



Atomic emission spectra
Photo illustrated by: Donnie Ray Obina

How did Neils Bohr explain the spectral lines of an element shown in the spectroscope? Each line in the atomic spectra of elements suggest definite energy transformations within the atom. Bohr stated that electrons are moving around the nucleus in circular path or orbit at definite distances from the nucleus. This is similar to the planets revolving around the sun. Electrons in each orbit have definite energy. This energy increases as the distance of the orbit from the nucleus increases. These **orbits** are also known as "**shells**" or "**energy levels**" and are assigned each a number: n=1, n=2, n=3, etc. or letters (K, L, M, N, O, etc.). As long as the electron stays in its given orbit, there is no absorption or emission of energy. If the electron received extra energy, it can jump into a higher energy level, this is also called **excited state**. The electron in the excited state can return to its original lower energy level or **ground state** by releasing discreet amount of energy in the form of light.

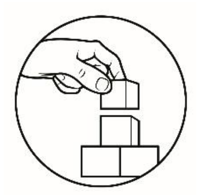


Absorption and Emission of Energy

Bohr's atomic model can only describe atomic spectrum of an atom having only one electron like that of hydrogen. An Austrian physicist, Erwin Schrodinger together with Werner Heisenberg and Louis de Broglie made a refinement of Bohr's atomic model. Schrödinger used mathematical equations to describe the possibility of finding an electron in a certain location. This model is known as the quantum mechanical model of the atom.

Based on the quantum mechanical model, it would be impossible to plot a definite path or orbit for the moving electrons. At least, we can only guess the most probable location of the electron in a given instant to be within a certain volume or region of space surrounding the nucleus. An **atomic orbital** is the region around the nucleus where the electron is most likely to be found. The atomic orbital serves as the "house" of the electron. It can accommodate a maximum of 2 electrons.

Aside from the main energy levels and atomic orbitals, there are also **energy sublevels** as shown by the finer lines in the atomic emission spectra of elements.



What's More

This atomic model presented by Bohr is comparable to a staircase as shown on the figure below. When you walk up or down the stairs your feet must hit the steps not on the empty space between each steps, otherwise you will be in trouble until you hit another step. The higher you climb the stairs; the more energy you need. Similarly, the electrons can only stay in a definite energy level and not on the space between energy levels. The further the energy level from the nucleus, the higher the energy.

Photo illustrated by: Donnie Ray Obina

Activity 1

Refer to the illustration above to answer the questions below.

1. Similar with the electron, what does the man require to climb up the stairs?
2. When going up the stairs, is it possible to reach the top instantly? (represent man as electron when explaining)
3. What happens to a person attempting to step on the next level with insufficient energy? (represent man as electron when explaining)
4. Can electrons occupy any space between energy levels?

Activity 2. Maximum Electron Capacity of the Main Energy Level

The maximum number of electrons in the main energy level is determined by the formula **$2n^2$** where n is an integer that designates each energy level. For the first main energy level (K), n=1; in the second main energy level (L), n=2, in the third energy level, n= 3 and so on. Each main energy level contains sublevels and each sublevel has a fixed number of atomic orbitals. For the s sublevel, there is only one atomic orbital, p sublevel has three atomic orbitals and d has 5 atomic orbitals.

Ex. In Main energy level 1 (K), n=1

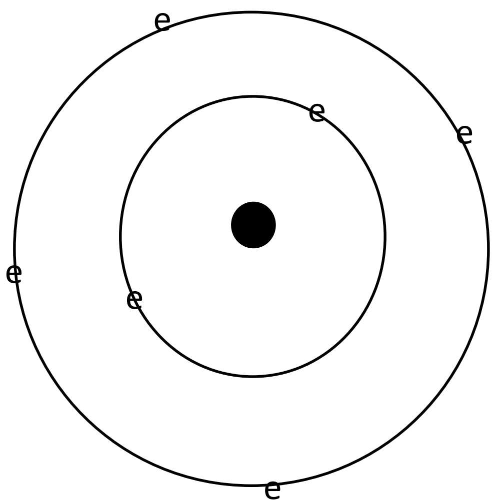
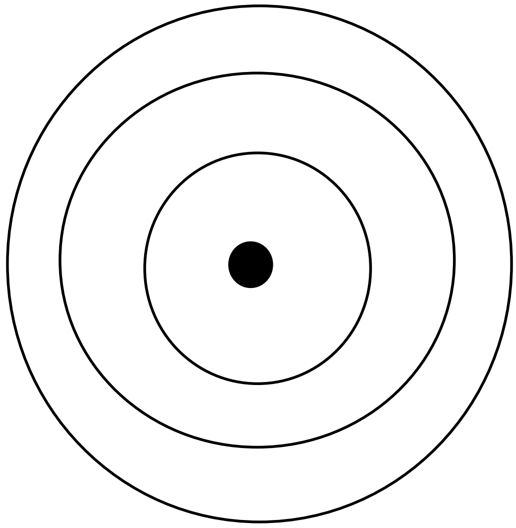
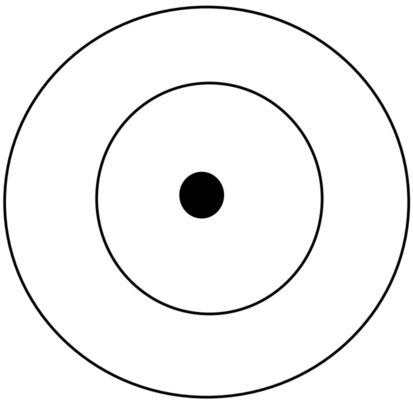
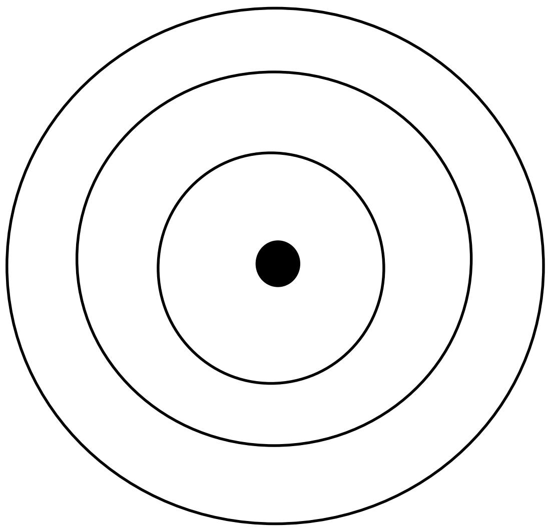
Using the formula $2n^2$, the number of electrons occupying energy level 1 is 2. Since there are 2 electrons in the first energy level, it means there is only one sublevel named s with one atomic orbital and that is the s orbital. How many sublevels and atomic orbitals are there in the next energy levels? Study the table below and supply the missing data.

Complete the table below

Main Energy Levels (n)	Number and kind of sublevels	Number of atomic orbital	kind of atomic orbitals	Maximum number of electrons)
1 (K)	1 (s)	1	1 s	2
2 (L)	2 (s and p)	4	1 s 3 p	8
3 (M)	3 (s, p, and d)	9	1 s 3 p 5 d	
4 (N)	4 (s, p, d, and f)	16	1 s 3 p 5d 7 f	32
5 (O)	5 (s, p, d, f, and g)	25		50
			1 s 3 p 5d 7 f 9 g 11 h	
7 (Q)				98

What I Have Learned

Illustrate the atomic model of the given elements.

 Carbon (C) atom has 6 electrons	 Magnesium (Mg) atom has12 electrons
 Beryllium (Be) atom has 4 electrons	 Chlorine (Cl) atom has 17 electrons

What I Can Do

Luksong tinik is one of our traditional games which originated in Cabanatuan city. As the height of the barrier (tinik) increases, why do players move away before jumping? Relate your answer to the energy of an electron as its distance from the nucleus increases.

Photo illustrated by: Donnie Ray Obina

Lesson 2	Electron Configuration

What's In

Matter is composed of atoms. Atoms are made up subatomic particles namely protons, neutrons, and electrons. The position of electrons within the atoms plays a vital role in the way atoms interact with one another to form compounds.

In lesson 1, you learned that electron can only stay at certain fixed distances away from the nucleus. This position is called energy levels. Each energy levels contain a certain number of sublevels. Every sublevel has fixed number of atomic orbitals. This atomic orbital is the place where electrons are most probably found. The electrons in the atomic orbital carries a definite amount of energy.

Tracking down the location of a given electron in an atom is similar to tracking where a person lives. To find this person you need to know his complete home address: City, Barangay, and house number. These corresponds to energy levels, sublevels, and atomic orbitals in an atom.

In order to track where all the electrons in an atom are, chemists use notation called electron configuration. This electron configuration is the most stable arrangement in which the electrons have the lowest energy. An example of electron configuration is $1s^22s^22p^6$ for neon atom. Do you know how this electron configuration is obtained? You will find out in this lesson.

What I Need to Know

At the end of the lesson, you will be able to:

1. Determine the pattern of filling the atomic orbitals based on the given electron distribution of the first 10 elements.
2. Write the electron configuration of the elements in the third period of the periodic table.

What's New

The electrons and the nucleus interact to make the most stable arrangement possible. The way in which electrons are distributed in the different orbitals around the nucleus is called the electron configuration.

Table 1: Distribution of electrons in the atomic orbitals of the first 10 elements.

Elements	**atomic orbitals**									**Electron Configuration**
	1s	**2s**	**$2p_x$**	**$2p_y$**	**$2p_z$**	**3s**	**$3p_x$**	**$3p_y$**	**$3p_z$**	
H_1	↑									$1s^1$
He_2	↑↓									$1s^2$
Li_3	↑↓	↑								$1s^22s^1$
Be_4	↑↓	↑↓								$1s^22s^2$
B_5	↑↓	↑↓	↑							$1s^22s^22p^1$
C_6	↑↓	↑↓	↑	↑						$1s^22s^22p^2$
N_7	↑↓	↑↓	↑	↑	↑					$1s^22s^22p^3$
O_8	↑↓	↑↓	↑↓	↑	↑					$1s^22s^22p^4$
F_9	↑↓	↑↓	↑↓	↑↓	↑					$1s^22s^22p^5$
Ne_{10}	↑↓	↑↓	↑↓	↑↓	↑↓					$1s^22s^22p^6$

Q1. Do you see any pattern in the electron configuration of the elements?
Q2. What are these patterns?

What is It

In the electron configuration of **$1s^2$**, 1 refers to the main energy level occupied by the electron, **s** denotes the kind of orbital and the superscript **2** for the number of electrons in the orbital. The main energy level also tells as the number of sublevels and the name of the sublevel is also the same with the name of the orbital.

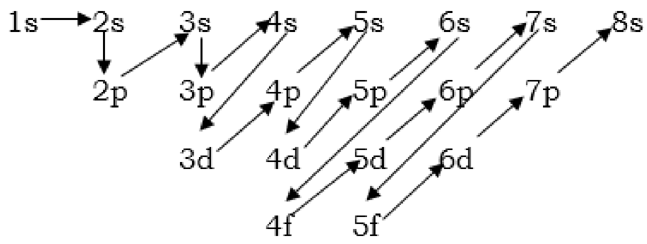
$1s^2$ → No. of electrons

energy level ↙ ↘ orbital type

Three rules are applied in deriving the electron configuration. These are Aufbau's Principle, Pauli's Exclusion Principle, and Hund's rule of multiplicity.

1. **Aufbau's Principle** is also known as the "building-up" principle, states that electron's occupy orbitals in order of increasing energy.

   It follows this mnemonic in filling up the orbital:

   Example:

   Write the electron configuration of

   a. Li-3
      Li-3: $1s^2\ 2s^1$

   b. Na-11
      Na-11: $1s^2\ 2s^2\ 2p^6\ 3s^1$

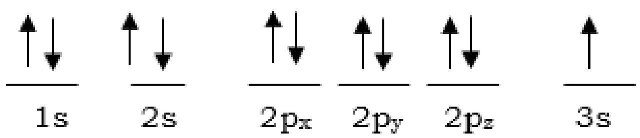
2. **Pauli's Exclusion Principle**
   Electrons occupying the same orbital must have opposite spin ↑↓.

   Example:

   a. Consider the electron configuration of Lithium: $1s^2\ 2s^1$
      Orbital diagram:

   b. Consider the electron configuration of Sodium: $1s^2\ 2s^2\ 2p^6\ 3s^1$
      Orbital diagram:

3. **Hund's rule of Multiplicity**

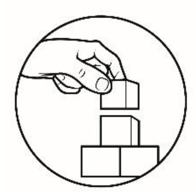
When electrons enter a sublevel with more than one orbital, they will spread out to the available orbitals with the same spin before pairing.

Example:

Consider the electron configuration of Nitrogen: $1s^2\ 2s^2\ 2p^3$

Orbital diagram:

N-7:	↑↓	↑↓	↑	↑	↑
	1s	2s	$2p_x$	$2p_y$	$2p_z$



What's More

Write the electron configuration of the elements and show the orbital diagram using the Hund's Rule and Pauli's Principle.

Elements	Orbital Diagram	Electron Configuration
Be_4	↑↓ ↑↓ 1s 2s	$1s^2\ 2s^2$
Mg_{12}		
Al_{13}		
Si_{14}		
P_{15}		

What I Have Learned

1. Which statement is NOT correct for an atom with an electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^5$?
   A. It has 17 electrons
   B. It has 3 main energy levels.
   C. The 3p orbitals are completely field.
   D. The s orbitals are completely filled.

2. Which electron configuration below is correct?
   A. $1s^2 2s^2 2p^5 3s^2 3p^6$
   B. $1s^2 2p^6 3s^2 3p^3$
   C. $1s^2 2s^2 3s^2 2p^6 3p^4$
   D. $1s^2 2s^2 2p^6 3s^2 3p^4$

3. Which is the correct configuration of P_{15} using the Hund's Rule.
   A. $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^1\ 3p_z$
   B. $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^1\ 3p_y^1\ 3p_z^1$
   C. $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^1\ 3p_y^1\ 3p_z\ 4s^1$
   D. $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^1\ 3p_y\ 3p_z^1\ 4s^1$

4. Write the electron configuration of Ca_{20} and show its orbital diagram.

Elements	**Orbital Diagram**	**Electron Configuration**
Ca_{20}		

What I Can Do

Have you noticed the nutrient label in your favorite snack? What are the elements present in it? List five (5) elements present in your snack and make an element card which shows the element name, element symbol, atomic number and electron configuration. Use short bond paper and cut into four for your card.

N-7
Nitrogen
$1s^2 2s^2 2p^2 3s^1$

Summary

- Bohr's atomic model describes the atom like a solar system, where the electron is found only in specific circular paths, or orbits around the nucleus. Electrons in each orbit has fixed energy.
- An electron can jump to a higher energy level by gaining energy and return to a lower energy level by releasing energy in the form of light.
- The Bohr model was later replaced by a model of the atom that showed that electrons are not limited to fixed orbits around the nucleus.
- Schrodinger formulated a mathematical equation that describes the behavior of the electron. The solution to the equation is used to calculate the probability of finding the electron at a particular region in space around the nucleus called atomic orbital.
- The quantum mechanical model of the atom describes the atom as having a nucleus at the center around which the electrons move. This model describes a region in space where the electron is most likely to be found.
- The distribution of electrons in the different atomic orbitals is called electron configuration.

Assessment

A. Multiple Choice: Select the letter of the best answer from among the given choices. Write it on a separate sheet of paper.

1. Which statement below supports the Bohr's model of the atom?
   A. The model accounted for the absorption spectra of atoms but not for the emission spectra.
   B. The model was accounted for describing the electron to be moving in definite orbits around the nucleus.
   C. The model was based on the wave properties of the electron.
   D. The model accounted for the emission spectra of atoms, but not for the absorption spectra.

2. Which orbital designation has the highest energy?
   A. 2p B. 3p C.3d D. 4s

3. What happens when an electron jumps from higher to lower energy level?
   A. colored light is given off
   B. the atom becomes excited
   C. another electron goes from a low energy level to a high one
   D. this process is not possible

4. Who among the scientist did not contribute to the development of the quantum mechanical model of the atom?
   A. Werner Karl Heisenberg C. Erwin Schrodinger
   B. Louie de Broglie D. Neils Bohr

5. How many electrons can each p orbital hold?
   A. 1 B. 2 C. 4 D.6

B. Shown here are the orbital configurations for the elements named. Each configuration is incorrect in some way. Identify the error in each and write the correct configuration.

6. Aluminum-13 : $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3d_1^1$
7. Chlorine-17 : $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 4s^1$
8. Neon-10 : $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^1\ 3s^1$
9. Potassium-19 : $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^2\ 3d_1^1$
10. Nitrogen-7 : $1s^2\ 2s^2\ 2p_x^2\ 2p_y^1$

Answer Key

What I Know	Assessment
1. D	1. B
2. A	2. C
3. D	3. A
4. C	4. D
5. D	5. B
6. B	6. $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^1$
7. C	7. $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^1$
8. C	8. $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2$
9. D	9. $1s^2\ 2s^2\ 2p_x^2\ 2p_y^2\ 2p_z^2\ 3s^2\ 3p_x^2\ 3p_y^2\ 3p_z^2 4s^1$
10. B.	10 correct

Lesson 1

What's New

1. Each element produced its own characteristic color.
2. The color of the flame will be the same. It is Na atom that will give color to the flame.

What's More

Activity 1

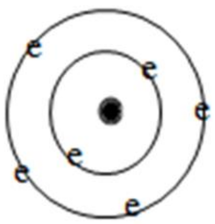
1. Energy
2. Not possible
3. The person cannot climb to the next step
4. no

Activity 2

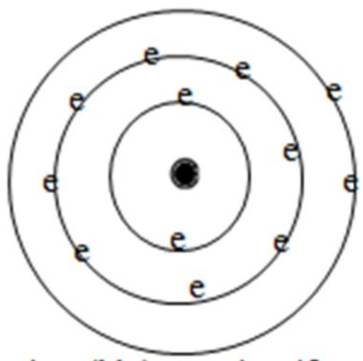
Main Energy Levels (n)	*Number and kind of sublevels*	*Number of atomic orbital*	*kind of atomic orbitals*	*Maximum number of electrons)*
1 (K)	1 (s)	1	1 s	2
2 (L)	2 (s and p)	4	1 s 3 p	8
3 (M)	3 (s, p, and d)	9	1 s 3 p 5 d	18
4 (N)	4 (s, p, d, and f)	16	1 s 3 p 5d 7 f	32
5 (O)	5 (s, p, d, f, and g)	25	1 s 3 p 5d 7 f 9 g	50

6 (P)	6 (s, p, d, f, g,and h)	36	1 s 3 p 5d 7 f 9 g 11 h	72
7 (Q)	6 (s, p, d, f, g, h, and i)	49	1 s 3 p 5d 7 f 9 g 11 h 13 i	98

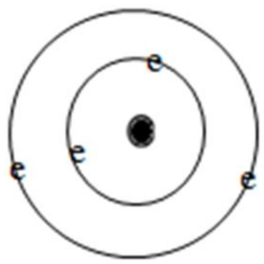
What I have learned



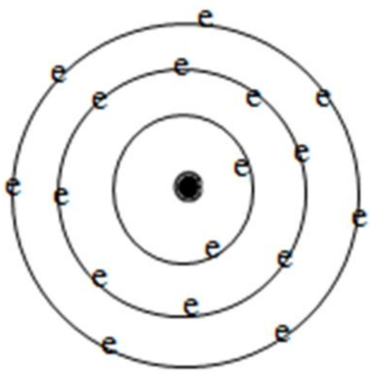
Carbon (C) atom has 6 electrons



Magnesium (Mg) atom has12 electrons



Beryllium (Be) atom has 4 electrons



Chlorine (Cl) atom has 17 electrons

What I can do

Players move farther from the barrier (tinik) to gain bigger energy so they can jump higher

Lesson 2

What's New

1. yes
2. •Electron's occupy orbitals in order of increasing energy.
   •There are 2 electrons occupying an orbital with opposite spin ↑↓.
   •An orbital in the same sublevel is filled with one electron of the same spin before pairing.

What's More

Elements	Orbital Diagram	Electron Configuration
Be_4	↑↓ ↑↓ 1s 2s	$1s_2\ 2s^2$
Mg_{12}	↑↓ ↑↓ ↑↓ ↑↓ ↑↓ 1s 2s 2px 2py 2pz ↑↓ 3s	$1s^22s^22p^63s^2$
Al_{13}	↑↓ ↑↓ ↑↓ ↑↓ ↑↓ 1s 2s 2px 2py 2pz ↑↓ ↑ __ __ 3s 3px 3py 3pz	$1s^22s^22p^63s^23p^1$
Si_{14}	↑↓ ↑↓ ↑↓ ↑↓ ↑↓ 1s 2s 2px 2py 2pz ↑↓ ↑ ↑ __ 3 3px 3py 3pz	$1s^22s^22p^63s^23p^2$
P_{15}	↑↓ ↑↓ ↑↓ ↑↓ ↑↓ 1s 2s 2px 2py 2pz ↑↓ ↑ ↑ ↑ 3s 3px 3py 3pz	$1s^22s^22p^63s^23p^3$

What I have Learned?

1. C
2. D
3. B
4.

Elements	Orbital Diagram	Electron Configuration
Ca_{20}	↑↓ ↑↓ ↑↓ ↑↓ ↑↓ 1s 2s $2p_x$ $2p_y$ $2p_z$ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ 3s $3p_x$ $3p_y$ $3p_z$ 4s	$1s^22s^22p_x^22p_y^22p_z^23s^23p_x^23p_y^23p_z^24s^2$

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For inquiries or feedback, please write or call:

Department of Education - Bureau of Learning Resources (DepEd-BLR)

Ground Floor, Bonifacio Bldg., DepEd Complex
Meralco Avenue, Pasig City, Philippines 1600

Telefax: (632) 8634-1072; 8634-1054; 8631-4985

Email Address: blr.lrqad@deped.gov.ph * blr.lrpd@deped.gov.ph