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5 Electrons in Atoms

Big idea ELECTRONS AND THE STRUCTURE OF ATOMS

5.1 Revising the Atomic Model

For students using the Foundation edition, assign problems 1–5, 7–11, 14.

Essential Understanding An electron's energy depends on its location around the nucleus of an atom.

Reading Strategy

Frayer Model The Frayer Model is a vocabulary development tool. The center of the diagram shows the concept being defined, while the quadrants around the concept are used for providing the details. Use this model when you want to understand a vocabulary term in more detail.

As you read Lesson 5.1, use the Frayer Model below. Place the term *quantum mechanical model* in the center of the model. Use the details you place in the appropriate quadrant to help you understand the vocabulary term.

Definition in your own words	Facts/characteristics
The quantum mechanical model shows where electrons are likely to be found in an atom and states the allowable energy levels an electron can have in a certain atom.	*The area where electrons are most likely to be found is called the electron cloud. This is based on mathematics, not experiments. It is used to predict the probability of an electron's location, but not its exact location.*
Examples	**Nonexamples**
electrons located in the electron cloud, the area where they are most likely to be found	*electrons in the nucleus or extremely far away from the nucleus (outside the electron cloud)*

Center: *quantum mechanical model*

EXTENSION **Read through the details you wrote in the Frayer Model. If the details do not include all the vocabulary terms from this lesson, add details that show how the other vocabulary terms in the lesson relate to the quantum mechanical model.**

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Lesson Summary

Energy Levels in Atoms Electrons in atoms are found in fixed energy levels.

- Niels Bohr proposed that electrons move in specific orbits around the nucleus.
- In these orbits, each electron has a fixed energy called an energy level.
- A quantum of energy is the amount of energy needed to move an electron from one energy level to another.

The Quantum Mechanical Model The quantum mechanical model determines how likely it is to find an electron in various locations around the atom.

- The quantum mechanical model is based on mathematics, not on experimental evidence.
- This model does not specify an exact path an electron takes around the nucleus, but gives the probability of finding an electron within a certain volume of space around the nucleus.
- This volume of space is described as an electron cloud, which has no boundary. The electron cloud is denser where the probability of finding the electron is high.

Atomic Orbitals An atomic orbital describes where an electron is likely to be found.

- Numbered outward from the nucleus, each energy level is assigned a principal quantum number, n, which is also the number of sublevels.
- Each energy sublevel differs in shape and orientation and contains orbitals, each of which can contain up to two electrons.
- Each energy level contains a maximum of $2n^2$ electrons.

After reading Lesson 5.1, answer the following questions.

Energy Levels in Atoms

1. Complete the table about atomic models and the scientists who developed them. Refer to Chapter 4 if you need to.

Scientist	Model of Atom
Dalton	***The atom is a tiny, indestructible particle with no internal structure.***
Thomson	***The atom is a sphere of positive electrical charge with electrons embedded in the sphere.***
Rutherford	***Most of an atom's mass is concentrated in the small, positively charged nucleus. The electrons are in motion in the space around the nucleus.***
Bohr	***Electrons move in circular orbits at fixed distances from the nucleus.***

2. Is the following sentence true or false? The electrons in an atom can exist between energy levels. ***false***

3. What are the fixed energies of electrons called?

energy levels

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4. Circle the letter of the term that completes the sentence correctly. A quantum of energy is the amount of energy required to

a. place an electron in an energy level.

b. maintain an electron in its present energy level.

(c.) move an electron from its present energy level to a higher one.

5. In general, the higher the electron is on the energy ladder, the ***farther*** ______ it is from the nucleus.

The Quantum Mechanical Model

6. What is the difference between the previous models of the atom and the modern quantum mechanical model?

Previous models described the motion of electrons in the same way as the motion of large objects. The quantum mechanical model uses mathematical equations to describe the behavior of electrons.

7. Is the following sentence true or false? The quantum mechanical model of the atom estimates the probability of finding an electron in a certain position.
true

Atomic Orbitals

8. A(n) ***atomic orbital*** ______ is often thought of as a region of space in which there is a high probability of finding an electron.

9. Circle the letter of the term that is used to label the energy levels of electrons.

a. atomic orbitals

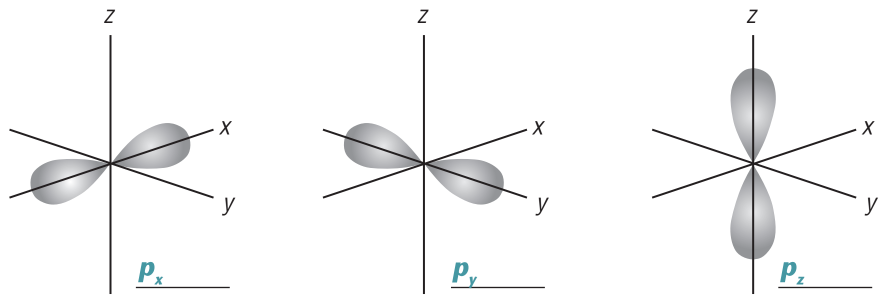
b. quantum mechanical numbers

c. quantum

(d.) principal quantum numbers (n)

10. The letter ***s*** ______ is used to denote a spherical orbital.

11. Label each diagram below p_x, p_y, or p_z.



p orbitals

12. Use the diagram above. Describe how the p_x, p_y, and p_z orbitals are similar.

The p orbitals are similar because they are all dumbbell-shaped.

13. Describe how the p_x, p_y, and p_z orbitals are different.

They differ in orientation. They are all perpendicular.

14. Circle the letter of the formula for the maximum number of electrons that can occupy a principal energy level. Use n for the principal quantum number.

(a.) $2n^2$ b. n^2 c. $2n$ d. n

5.2 Electron Arrangement in Atoms

For students using the Foundation edition, assign problems 2–6, 9–11.

Essential Understanding Three rules determine the electron arrangement in an atom: the aufbau principle, the Pauli exclusion principle, and Hund's rule.

Lesson Summary

Electron Configurations An electron configuration describes the arrangement of electrons in an atom.

- The aufbau principle says that electrons occupy the orbitals of lowest energy first.
- According to the Pauli exclusion principle, each orbital can contain at most two electrons. The two electrons must have opposite spin.
- Hund's rule states that single electrons occupy orbitals in a specific sublevel until each orbital contains an electron. Then electrons pair with these single electrons.
- Some electron configurations are exceptions to these rules because of the relative stability of half-full sublevels.

After reading Lesson 5.2, answer the following questions.

Electron Configurations

1. The ways in which electrons are arranged into orbitals around the nuclei of atoms are called *electron configurations*.

Match the name of the rule used to find the electron configurations of atoms with the rule itself.

b 2. aufbau principle

c 3. Pauli exclusion principle

a 4. Hund's rule

a. When electrons occupy orbitals of equal energy, one electron enters each orbital until all the orbitals contain one electron with the same spin direction.

b. Electrons occupy orbitals of lowest energy first.

c. An atomic orbital may describe at most two electrons.

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5. Look at the aufbau diagram, Figure 5.5. Which atomic orbital is of higher energy, a 4*f* or a 5*p* orbital? ***4f***

6. Fill in the electron configurations for the elements given in the table. Use the orbital filling diagrams to complete the table.

Electron Configurations for Some Selected Elements

Element	Orbital filling 1*s*	2*s*	$2p_x$	$2p_y$	$2p_z$	3*s*	Electron configuration
H	↑						$1s^1$
He	↑↓						$1s^2$
Li	↑↓	↑					$1s^22s^1$
C	↑↓	↑↓	↑	↑			$1s^22s^22p^2$
N	↑↓	↑↓	↑	↑	↑		$1s^22s^22p^3$
O	↑↓	↑↓	↑↓	↑	↑		$1s^22s^22p^4$
F	↑↓	↑↓	↑↓	↑↓	↑		$1s^22s^22p^5$
Ne	↑↓	↑↓	↑↓	↑↓	↑↓		$1s^22s^22p^6$
Na	↑↓	↑↓	↑↓	↑↓	↑↓	↑	$1s^22s^22p^63s^1$

7. In an electron configuration, what does a superscript stand for?

The superscript stands for the number of electrons occupying a given sublevel.

8. In an electron configuration, what does the sum of the superscripts equal?

The sum equals the number of electrons in the atom.

9. Is the following sentence true or false? Every element in the periodic table follows the aufbau principle. ***false***

10. Filled energy sublevels are more ***stable*** than partially filled sublevels.

11. Half-filled levels are not as stable as ***filled*** levels, but are more stable than other configurations.

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5.3 Atomic Emission Spectra and the Quantum Mechanical Model

For students using the Foundation edition, assign problems 1–8, 10, 15–18.

Essential Understanding The electromagnetic radiation emitted by excited electrons returning to a lower energy level is unique for that particular element and is based on differences in energy among energy levels in the atom.

Lesson Summary

Light and Atomic Emission Spectra When electrons lose energy, they emit light of specific wavelengths when they return to lower energy levels.

- Each electromagnetic wave has a wavelength (λ) and a frequency (ν) related by the equation $c = \lambda\nu$, where c is the speed of light.
- When atoms absorb energy, their electrons move to a higher energy level.
- When excited electrons lose energy, they emit a unique set of light waves, known as the atomic emission spectrum, for that element.

The Quantum Concept and Photons Photons are units of light that behave like particles.

- Max Planck proposed that the energy of a body changes only in quanta, which are small, discrete units.
- Planck's theory helped explain the photoelectric effect, which happens when electrons are ejected from matter under certain wavelengths of light.
- Quantum theory implies that light behaves both as a wave and as a particle.

An Explanation of Atomic Spectra The lines in an element's atomic spectrum result from electrons moving from a higher to a lower energy level.

- The lowest energy level an electron occupies is its ground state.
- The frequency of the light emitted when an electron drops from a higher energy level to a lower one is proportional to the energy change of the electron.

Quantum Mechanics Quantum mechanics describes the motions of extremely small particles, such as electrons, as waves.

- Experiments confirm that light behaves both as waves and particles.
- All moving particles act as waves, but larger objects have wavelengths too small to observe.
- The Heisenberg uncertainty principle states that it is impossible to know both the velocity and the location of a particle at the same time.

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BUILD Math Skills

Algebraic Equations An algebraic equation shows the relationship between two or more variables. Often, an equation must be solved for the unknown variable before substituting the known values into the equation and doing the arithmetic.

Most equations can be solved if you remember that you can perform any mathematical operation without destroying equality as long as you do it to both sides of the equals sign.

Sample Problem What is the volume of 622 g of lead if the density of lead is 11.3 g/cm^3?

List the knowns and the unknown.

You know that *g* is a measure of mass, so 622 g is the mass of lead.

KNOWNS	UNKNOWN
Mass (m) = 622 g	(v) Volume
Density (d) = 11.3 g/cm^3	

Solve for the unknown.

Start with the formula.

$$d = \frac{m}{v}$$

Since you're looking for *v*, get *v* to one side. You do this by multiplying **both** sides by $\frac{v}{d}$.

$$\not{d} \times \frac{v}{\not{d}} = \frac{m}{\not{v}} \times \frac{\not{v}}{d}$$

$$v = \frac{m}{d}$$

Solve.

$$v = \frac{m}{d} = \frac{622\ \text{g}}{11.3\ \text{g/cm}^3} = 55.04\ \text{cm}^3$$

Now it's your turn to practice solving algebraic equations. Answer the following questions.

1. A football field that is 60 m wide and 110 m long is being paved over to make a parking lot. The builder ordered 660,000,000 cm^3 of cement. How thick must the cement be to cover the field using 660,000,000 cm^3 of cement? (Use the formula $V = l \times w \times h$.)

   10 centimeters thick

2. X-rays are used to diagnose diseases of internal body organs. What is the frequency of an X-ray with a wavelength of 1.15×10^{-10} m?

   2.61×10^{18} Hz

3. What is the speed of an electromagnetic wave with a frequency of 1.33×10^{17} Hz and a wavelength of 2.25 nm?

   $v = 3.00 \times 10^{8}$ m/s

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After reading Lesson 5.3, answer the following questions.

Light and Atomic Emission Spectra

4. Match each term describing waves to its definition.

___*b*___ amplitude

___*a*___ wavelength

___*c*___ frequency

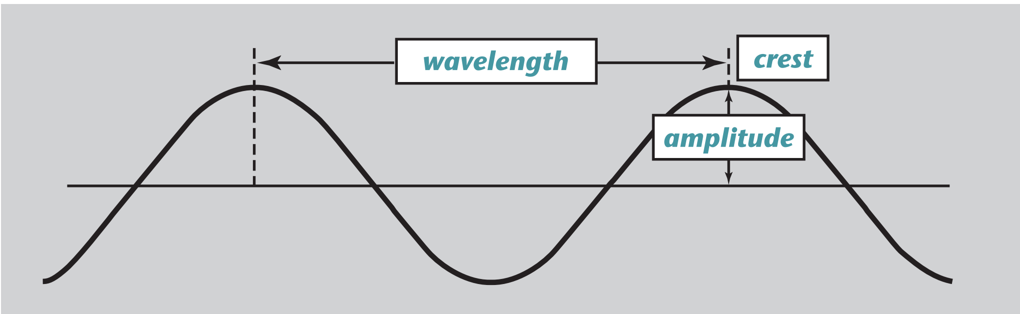
a. the distance between two crests

b. the wave's height from zero to the crest

c. the number of wave cycles to pass a given point per unit of time

5. The units of frequency are usually cycles per second. The SI unit of cycles per second is called a(n) ***hertz (Hz)***______.

6. Label the parts of a wave in this drawing. Label the wavelength, the amplitude, and the crest.



7. The product of wavelength and frequency always equals a(n) ***constant (c)***______, the speed of light.

8. Is the following sentence true or false? The wavelength and frequency of light are inversely proportional. ***true***______

9. Light consists of electromagnetic waves. What kinds of visible and invisible radiation are included in the electromagnetic spectrum?

radio waves, microwaves, infrared waves, visible light, ultraviolet waves, X-rays, and gamma rays

10. When sunlight passes through a prism, the different wavelengths separate into a(n) ***spectrum***______ of colors.

11. Put the visible colors in order of increasing frequency.

___*2*___ orange ___*6*___ violet ___*5*___ blue

___*4*___ green ___*3*___ yellow ___*1*___ red

12. Look at Figure 5.8. The electromagnetic spectrum consists of radiation over a broad band of wavelengths. What type of radiation has the lowest frequency? The highest frequency?

Radio waves have the lowest frequency. Gamma rays have the highest frequency.

13. What happens when an electric current is passed through the gas or vapor of an element?

The atoms absorb energy, which causes them to emit light.

14. Passing the light emitted by an element through a prism gives the *atomic emission spectrum* of the element.

15. Is the following sentence true or false? The emission spectrum of an element can be the same as the emission spectrum of another element. *false*

16. Only electrons moving from *higher* to *lower* energy levels lose energy and emit light.

The Quantum Concept and Photons

17. What did Albert Einstein call the quanta of light energy? *photons*

An Explanation of Atomic Spectra

18. What is the lowest possible energy of an electron called? *ground state*

Quantum Mechanics

19. What does de Broglie's equation predict about the behavior of particles?
It predicts that all moving objects have wavelike behavior.

20. Is the following sentence true or false? Quantum mechanics describes the motions of subatomic particles and atoms as waves. *true*

21. According to the Heisenberg uncertainty principle, it is impossible to know exactly both the *velocity* and the *position* of a particle at the same time.

22. Does the Heisenberg uncertainty principle apply to cars and airplanes?
No, it applies only to small particles.

Guided Practice Problem

Answer the following questions about Practice Problem 15.

What is the wavelength of radiation with a frequency of 1.50×10^{13} Hz? Does this radiation have a longer or shorter wavelength than red light?

Analyze

Step 1. What is the equation for the relationship between frequency and wavelength?
$c = \lambda \nu$

Step 2. What does *c* represent, and what is its value?
It represents the speed of light, which is 2.998×10^{8} *m/s.*

Step 3. What is the wavelength of red light in m?
Red light has a wavelength of about 7.0×10^{-7} *m.*

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Calculate

Step 4. Solve the equation for the unknown. $\lambda = \frac{c}{v}$

Step 5. Substitute the known quantities into the equation and solve.

$$\frac{2.998 \times 10^{8}\ \text{m/s}}{1.50 \times 10^{13}\ \text{s}} = 2.00 \times 10^{-5}\ \text{m}$$

Step 6. Compare the answer with the wavelength of red light. Does the given radiation have a wavelength longer or shorter than that of red light?

The answer, 2.00×10^{-5} m, is greater than the wavelength of red light, 7×10^{-7} m. Therefore, this radiation has a longer wavelength than red light.

Evaluate

Step 7. Explain why you think your result makes sense.

The magnitude of the frequency is about 10^{5} times the magnitude of c. Because frequency and wavelength are inversely proportional, the answer should be about 10^{-5}.

Step 8. Are the units in your answer correct? How do you know?

Yes; wavelength is measured in meters or fractions of a meter.

Apply the Big idea

Explain how each of these rules was used to write this electron configuration.

	1s	2s	2p	2p	2p	3s	3p	3p	3p	3d	3d	3d	3d	3d	4s
Co	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓	↑	↑	↑	↑↓

a. aufbau principle

Electrons fill lower energy sublevels first. In this example, 4s is filled before 3d because the levels overlap, and 4s has lower energy than 3d.

b. Pauli exclusion principle

No more than two electrons are in an orbital.

b. Hund's rule

Individual electrons were placed in all the d orbitals before pairing any of the electrons.

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5 Self-Check Activity

For Questions 1–9, complete each statement by writing the correct word or words. If you need help, you can go online.

5.1 Revising the Atomic Model

1. Bohr proposed that an electron is found only in specific circular paths, or ***orbits***, around the nucleus.

2. The ***quantum mechanical*** model describes the energy an electron can have and the probability of finding the electron in various locations around the nucleus of an atom.

3. Orbitals, which are found in ***sublevels***, have different shapes, depending on the energy of the electrons they contain.

5.2 Electron Arrangement in Atoms

4. Electron configurations can be written by using the ***aufbau principle***, the Pauli exclusion principle, and Hund's rule.

5.3 Atomic Emission Spectra and the Quantum Mechanical Model

5. When atoms absorb energy, their electrons move to higher ***energy levels***.

6. Describing light as ***quanta*** of energy that behave as particles helps to explain the photoelectric effect.

7. When an electron drops to a lower energy level, it emits light that has a ***frequency*** directly proportional to the energy change of the electron.

8. ***Classical mechanics*** describes the motion of large bodies.

9. ***Quantum mechanics*** describes the motion of very small particles, such as subatomic particles.

If You Have Trouble With...

Question	1	2	3	4	5	6	7	8	9
See Page	129	130	131	134	140	143	145	147	147

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Review Key Equations

Define each term in the following equations. If a term is a constant, include its value.

1. $c = \lambda \nu$

   c = the speed of light, 2.998×10^8 m/s   λ = wavelength   ν = frequency

2. $E = h\nu$

   E = amount of radiant energy of a single quantum absorbed or emitted by a body

   h = Planck's constant, 6.626×10^{-34} J·s   ν = frequency of radiation

3. If you know the value of E but do not know the value of ν, how can you find λ?

   Solve both equations for ν (ν = c/λ, ν = E/h). Set the values for ν equal to each other (c/λ = E/h). Solve for λ (λ = ch/E). Substitute the values for c, E, and h and calculate λ.

Review Vocabulary

In each of these sets of terms, circle the one term that does not belong. Then explain your reasoning. *Accept any answer students can justify.*

1. electron configuration, (Planck's constant), aufbau principle

   The aufbau principle shows how electrons are arranged to form electron configurations. Planck's constant relates the energy of a quantum and the frequency of radiation.

2. (spectrum), amplitude, wavelength

   Amplitude and wavelength are properties of waves, and spectrum is not.

3. (hertz), quantum, photon

   Photons are quanta of energy that behave as particles. Hertz is the unit of frequency.

4. Hund's rule, Pauli exclusion principle, (Heisenberg uncertainty principle)

   Hund's rule and the Pauli exclusion principle deal with electron configurations. The Heisenberg uncertainty principle does not.

5. atomic orbital, (frequency), energy level

   Atomic orbitals are in energy levels. Frequency is a wave property.