Study Guide for Module 7A—The Structure of the Atom

Reading Assignment: Sections 7.1-7.10 in *Chemistry, 6th Edition* by Zumdahl

Guide for Your Lecturer:

1. *Postulates of the Atomic Theory* (Review)
2. *An Overview of the Structure of the Atom* (Review)
✔ 3. *The Components of Chemical Species* (Review)
✔ 4. *The Nature of Light and Other Electromagnetic Radiation*
5. *Absorption and Emission Spectra*
6. *The Bohr Model of the Atom*
7. *Wave-Particle Duality*
✔ 8. *Wavefunctions and Quantum Numbers*
✔ 9. *Electron Density, Atomic Orbitals, and Energy Level Diagrams*
✔ 10. *Writing Electronic Configurations* (Aufbau Principle, Pauli Exclusion Principle, Hund's Rules, degenerate)

Homework

Note: ✔ indicates problems to be stressed on drill quizzes and hour exams.

■ ***Review from Module 2: The Postulates of the Atomic Theory of Matter***

1. State the four postulates of the atomic theory of matter. (p. 46-47)

-1)

-2)

-3)

-4)

■ ***Review from Module 2: An Overview of the Structure of the Atom***

2a) Complete the following table regarding the components of the atom. (p. 53, inside back cover of text)

particle	approx. mass in grams	approx. mass in amu	charge in coulombs	relative charge
electron	$9.11 * 10^{-28}$ g	$\sim \frac{1}{1800}$ amu	$-1.6 * 10^{-19}$ C	−1
proton	$1.673 * 10^{-24}$ g	~ 1 amu	$+1.6 * 10^{-19}$ C	+1
neutron	$1.675 * 10^{-24}$ g	~ 1 amu	0	0

b) Answer the following questions regarding the structure of the atom.

A. Give a general description of the manner in which electrons, protons, and neutrons are organized in the atom. (p. 52)

B. Where is the positive charge in an atom located? (p. 53-54)

■***Review from Module 2: An Overview of the Structure of the Atom (continued)***

2b) Answer the following questions regarding the structure of the atom.

C. Where is most of the mass of an atom? (p. 54)

D. Where are the neutrons in an atom? (p. 53)

E. What is the approximate radius of an atom? (p. 53)

F. If an atom were the size of the SuperDome, approximately how large would its nucleus be? (About the size of a green pea.)

G. Where is the negative charge in an atom? (Spread out in the volume outside the nucleus.)

c) Define nucleus (p. 53)

d) Define atomic number (p. 54)

e) Define mass number (p. 54)

f) Define nuclide (p. 818)

g) Define isotopes (p. 54)

✔✔✔■***Review from Module 2: The Components of Chemical Species***

3. Fill in the table for the chemical species below and be prepared to do so for any other atom or monoatomic ion. (pp. 56)

		Number of protons	Number of electrons	Number of neutrons	approx. mass	Charge on nucleus	Mass number	Atomic number	isotope
S.	$^{42}Ca^{+}$	20	19	22	42 amu	+20	42	20	$^{41}Ca^{+}$
A.	$^{40}Ar^{+}$	18	17	22	40 amu	+18	40	18	$^{41}Ar^{+}$
B.	$^{36}Cl^{-}$	17	18	19	36 amu	+17	36	17	$^{37}Cl^{-}$
C.	$^{77}As^{3+}$	33	30	44	77 amu	+33	77	33	$^{76}As^{+3}$
D.	$^{113}Cd^{2+}$	48	46	65	113 amu	+48	113	48	$^{114}Cd^{+2}$
E.	$^{66}Ga^{2-}$	31	33	35	66 amu	+31	66	31	$^{67}Ga^{-2}$

■*The Nature of Light and Other Electromagnetic Radiation*

4a) What do scientists generally use to study the arrangement of electrons in atoms. (Electromagnetic radiation.)

b) Define electromagnetic radiation. (p. 290, A 32)

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c) What is the speed at which electromagnetic radiation travels? (p. 291)

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d) List nine types of electromagnetic radiation in the first column below in order of increasing wavelength (*1: cosmic rays, 2: gamma rays, 8: TV, 9: FM radio, 10: AM radio*) (p. 293)

Name of Radiation	Variation in		
	Wavelength	Frequency	Energy
-1)			
-2)			
-3)			
-4)			
-5)			
-6)			
-7)			
-8)			
-9)			
-10)			

e) Complete the following table regarding the properties of electromagnetic waves. (p. 290)

Property	Defnition	Units
Wavelength		
Frequency		
Amplitude		
Velocity		

f) State the qualitative relationship between frequency and wavelength of electromagnetic radiation and then the equation which relates the two. (p. 291)
•Qualitative relationship:

•Equation:

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g) Scientists made a big advance in their understanding of electromagnetic radiation when Planck put forth a very unusual theory in 1900. (pp. 292-3)
•What did he postulate?

•Why did he suggest such an unusual theory?

■***The Nature of Light and Other Electromagnetic Radiation (continued)***

h) What does "quantized" mean? (Countable)

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i) Define photon. (A 38, p. 294)

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j) State the qualitative relationship between frequency and energy of electromagnetic radiation and then the equation which relates the two. (p. 294)
•Qualitative relationship:

•Equation:

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k) In columns two, three, and four in *4d*, show how frequency, wavelength, and energy of the types of electromagnetic radiation vary. (pp. 291-4)

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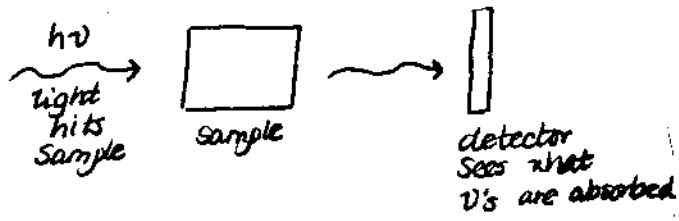
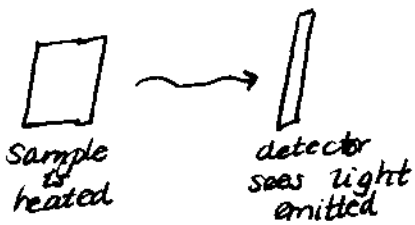
l) Modern scientists believe that electromagnetic radiation has a "dual nature." Explain what this means. (p. 295)

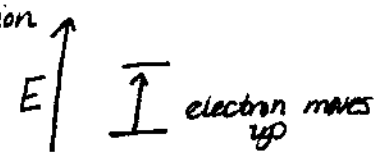
■***Absorption and Emission Spectra***

5a) Name, briefly describe, and then sketch diagrams of two types of experiments chemists might use to experimentally determine the distribution of electrons in atoms. (Absorption and emission of electromagnetic radiation.)

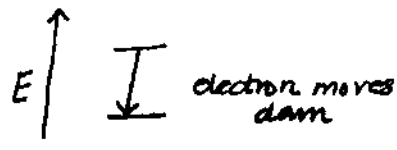
•Name: Absorption of Radiation Brief description: Electromagnetic radiation is allowed to hit the sample. If the ν of the radiation is appropriate, some of the radiation is absorbed as the e⁻ moves to higher energy.	Sketch: 
•Name: Emission of Radiation Brief description: Sample is heated which causes e⁻'s to go to higher energy levels. Electromagnetic radiation is emitted as the e⁻'s return to lowest level.	Sketch: 

b) List each of the names of the two types of experiments in *5a* above and draw an energy level diagram showing the movement of an electron in each.

• Absorption



• Emission



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c) Define spectrum. (A distribution of electromagnetic radiation ordered by wavelength. The rainbow is an example.)

■***Absorption and Emission Spectra***

d) Distinguish between a continuous and a discrete spectrum. (p. 298)

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e) •When the experiments in *5a* above are conducted, are the spectra obtained continuous or discrete?

•Explain what this tells us about the energy levels in atoms. (p. 297-8)

■***The Bohr Model of the Atom***

6a) In the late 19th century, knowledgeable people thought that all of the big discoveries of science had already been made. Then they discovered that the atom consisted of electrons surrounding a positively-charge nucleus. This presented a major problem. What was this problem?

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b) What did Bohr do differently to solve the problem in *6a* above?

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c) List four features of the Bohr model of the atom. (pp. 299-304)
-1)

-2)

-3)

-4)

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d) What were the primary data which Bohr's theory had to explain? (pp. 299-304)

■***Wave-Particle Duality***

7a) Briefly state what modern scientists believe regarding the nature of matter. (pp. 295-7).

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b) What are the conditions under which wave-particle duality becomes important in the ordinary world? (pp. 295-6)

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c) State the Heisenberg Uncertainty principle. (p. 305)

■ ***Wave-Particle Duality (continued)***

d) de Broglie postulated that matter, like light, has a dual nature and postulated a formula for calculating the wavelength of electromagnetic radiation associated with matter of a given mass and speed. State that equation. (pp. 295-7)

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e) Define Planck's constant, h, in Joules. (p. 293, $h = 6.626 * 10^{-34}$ J*s)

✔✔✔■ ***Wavefunctions and Quantum Numbers***

8a) Now we know that the electron has both wave and particle properties and can be described by a mathematical expression which allows you to calculate all the properties of the electron. This expression is called the wavefunction. Define wavefunction. (p. 305) (A mathematical expression that describes the particle as a function of the particle's coordinates. Given the symbol Ψ.)

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b) Define atomic orbital (p. 305) (A region of space that an electron can occupy.)

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c) Define quantum number (pp. 307-9) (Number which must be used in the expression for the wavefunction to be able to calculate the allowed energies.)

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d) List the symbols of the four quantum numbers used to characterize an electron in an atom, the names of each, the physical properties to which each is related, and the range of each. (pp. 307-12) **MEMORIZE**

Symbol	Name	Physical Property to which it is related	Range of Values
n	principal quantum #	size and energy of orbital	$n = 1, 2, 3, 4 \ldots$
ℓ	angular q.#	shape of orbital	$\ell = 0, 1, 2 \ldots (n-1)$
m	magnetic q.#	orientation of orbital	$m = 0, \pm 1, \pm 2, \ldots \pm \ell$
s	spin q.#	direction of spin of e⁻	$+\frac{1}{2}, -\frac{1}{2}$

e) Define shell as related to atomic orbitals. (A set of atomic orbitals with the same value of the n quantum number.)

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f) Define subshell as related to atomic orbitals. (A set of atomic orbitals with the same value of the n and l quantum numbers.)

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g) Complete the following table:

ℓ value	0	1	2	3	4
type of orbital	s	p	d	f	g

✔✔✔■ ***Electron Density, Atomic Orbitals, and Energy-Level Diagrams***

9a) A. Define electron density. (Electron density is the probability of finding the electron at a particular point if it is treated as a particle or the "thickness" of the cloud if the electron is treated as a wave.)

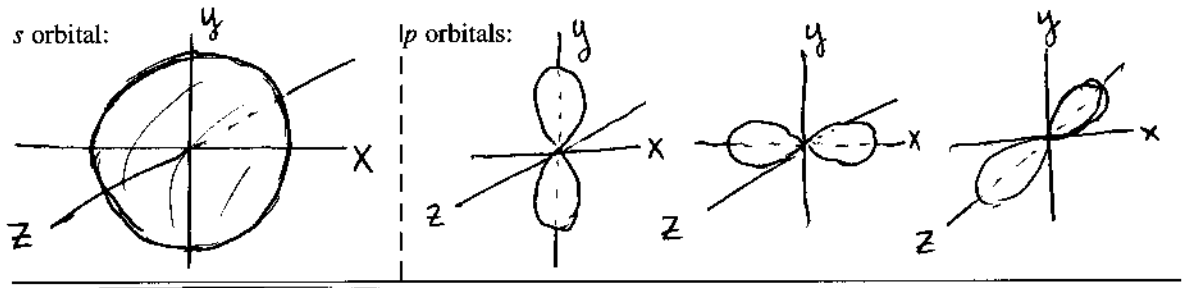
✔✔✔■***Atomic Orbitals, Electron Density, and Energy-Level Diagrams (continued)***

B. How is the electron density of an electron related to its wave function? (p. 306)

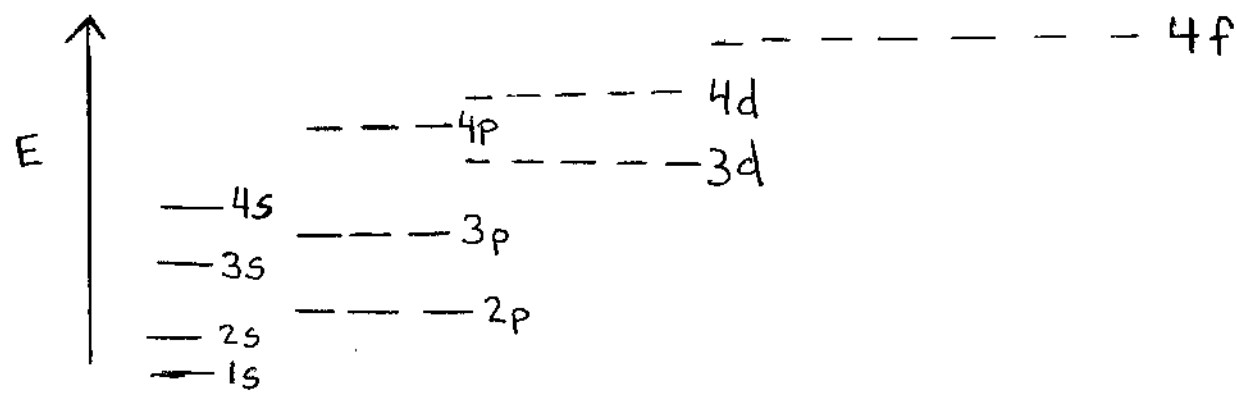
C. Define node with respect to a wave function. (p. 309

b) Sketch the following orbitals of the hydrogen atom. (pp. 309-10)

s orbital: *p* orbitals:



9c) Draw and label an energy level diagram showing all orbitals in the lowest four energy levels. **MEMORIZE**



✔✔✔■***Writing Electronic Configurations***

10a) A. State the Aufbau Principle. (p. 317)

B. State the Pauli Exclusion Principle. (p. 310, 312) Two electrons cannot occupy the same region of space--i.e. be in the same orbital--unless they have opposite spins. An alternate way of stating it is that no two electrons in an atom can have all four quantum numbers the same.)

C. Define degenerate with respect to atomic orbitals. (p. 309) (Having the same energy.)

D. State Hund's rule regarding the manner in which electrons fill into atomic orbitals. (p. 318)

b) What is the "ground state" of an atom? (p. 300)

✔✔✔■ ***Writing Electronic Configurations (continued)***

c) Use the information in *a* above to show the orbitals in which electrons are located if the indicated atom is in its ground state.

Atom: H *# e⁻'s:* 1 2p 2s E 1s *Summary of e⁻'s:* $1s^1$	*Atom:* He *# e⁻'s:* 2 2p 2s E 1s *Summary of e⁻'s:* $1s^2$	*Atom:* Li *# e⁻'s:* 3 2p 1 2s E 1s *Summary of e⁻'s:* $1s^2 2s^1$
Atom: Be *# e⁻'s:* 4 2p 2s E 1s *Summary of e⁻'s:* $1s^2 2s^2$	*Atom:* B *# e⁻'s:* 5 1 2p 2s E 1s *Summary of e⁻'s:* $1s^2 2s^2 2p^1$	*Atom:* C *# e⁻'s:* 6 1 1 2p 2s E 1s *Summary of e⁻'s:* $1s^2 2s^2 2p^2$

10d) The "summaries" of the location of electrons as shown above are called electronic configurations. While electronic configurations can be obtained from energy-level diagrams as shown in *d* above, it is easier to obtain them from a simple mnemonic. Draw that mnemonic below. (p. 323)

e) Write the order in which electrons usually fill into atomic orbitals using the mnemonic above. (p. 323)
MEMORIZE

f) An alternative to the mnemonic above is to use the periodic table to remember the order in which the atomic orbitals are filled. List which groups correspond to which subshells and in which energy shell each subshell starts.

Subshell	Groups	Energy shell where subshell starts
s	IA → IIA	1
p	IIIA → VIIIA	2
d	"B" elements (Transition Metals)	3
f	Lanthanides & Actinides	4

✔✔✔■ ***Writing Electronic Configurations (continued)***

g) Write the ground state electronic configurations of the following atoms. (pp. 317-24)

	Species/ No. electrons	Electronic Configuration	Species/ No. electrons	Electronic Configuration
S.	Al 13 e's	$1s^2 2s^2 2p^6 3s^2 3p^1$	C 6 e's	$1s^2 2s^2 2p^2$
A.	S 16 e's	$1s^2 2s^2 2p^6 3s^2 3p^4$	Mg 12 e's	$1s^2 2s^2 2p^6 3s^2$
B.	Ne 10 e's	$1s^2 2s^2 2p^6$	Sb 51 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^3$
C.	Fr 87 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6 7s^1$	Cl 17 e's	$1s^2 2s^2 2p^6 3s^2 3p^5$
D.	P 15 e's	$1s^2 2s^2 2p^6 3s^2 3p^3$	Se 34 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^4$
E.	Br 35 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$	Sr 38 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2$

10h) When anions are formed, electrons are added to additional orbitals in the same manner as for atoms above. When cations are formed, electrons are removed from the orbital with the highest value of *n* (if two subshells have the same value of *n*, they are lost from the one with the higher value of *l* first). For most atoms this means when cations are formed, the electrons are lost from the last subshell into which electrons were placed. Write the electronic configurations for the atom. Then remove or add electrons to form the given ion.

S.	C 6 e's	$1s^2 2s^2 2p^2$	C^+ 5 e's	$1s^2 2s^2 2p^1$
A.	Na 11 e's	$1s^2 2s^2 2p^6 3s^1$	Na^+ 10 e's	$1s^2 2s^2 2p^6$
B.	Al 13 e's	$1s^2 2s^2 2p^6 3s^2 3p^1$	Al^{3+} 10 e's	$1s^2 2s^2 2p^6$
C.	S 16 e's	$1s^2 2s^2 2p^6 3s^2 3p^4$	S^{2-} 18 e's	$1s^2 2s^2 2p^6 3s^2 3p^6$
D.	P 15 e's	$1s^2 2s^2 2p^6 3s^2 3p^3$	P^{2-} 17 e's	$1s^2 2s^2 2p^6 3s^2 3p^5$
E.	Si 14 e's	$1s^2 2s^2 2p^6 3s^2 3p^2$	Si^{2-} 16 e's	$1s^2 2s^2 2p^6 3s^2 3p^4$
F.	K 19 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$	K^+ 18 e's	$1s^2 2s^2 2p^6 3s^2 3p^6$
G.	I 53 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^5$	I^+ 52 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^4$
H.	Se 34 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^4$	Se^{2+} 32 e's	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^2$

■*Challenge Questions*

A. The energy of an electron in a hydrogen atom is given by the equation $E_n = -2.179*10^{-18}\ J/n^2$. Calculate the energy difference between the 2nd and 3rd energy levels in the hydrogen atom.

B. The energy of an electron in a hydrogen atom is given by the equation $E_n = -2.179*10^{-18}\ J/n^2$. Calculate the ionization potential of hydrogen. FYI: The ionization potential is the energy required to totally remove an electron from an atom, i.e. to move it from the wherever it is to the $n = \infty$ level.

C. The energy of an electron in a hydrogen atom is given by the equation $E_n = -2.179*10^{-18}\ J/n^2$. Draw an energy level diagram showing the four lowest energy levels for the electron in a hydrogen atom being sure to indicate the energies of each on the axis.

D. The energy of an electron in a hydrogen atom is given by the equation $E_n = -2.179*10^{-18}\ J/n^2$. State this relationship verbally. (i.e. State how E and *n* are related.)

E. The energy of an electron in a one-electron system is given by the equation $En = -2.179*10^{-18}\ Z^2/n^2$ J, where Z is the atomic number. What is the relationship between the n = 2 energy level of H and He^+?

F. What is the wavelength associated with a 5.0 ounce baseball thrown at 95 miles/hour? (16 oz = 1 lb, 5280 ft = 1 mile)

G. Which of the following correctly states the relationship between the n = 2 level of a He^+ atom (in which Z = 2) and the n = 2 level of a Li^{+2} ion (in which Z = 3)?

■*Bonding/Model Activity to Improve Ability to Visualize in 3-D*

Use the molecular model set you purchased for this course to assemble a model which has a tetrahedral shape.

Revised by Shay Vines, Spring 1997; Fall 1998; Mike Adams, Fall 1999; Donna Howell, Fall 2000; JWC, Fall 2001; SJB, Fall, 2002