

Chapter 4: Structure of the Atom

Complete Study Notes for Exam Preparation

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1. Introduction to Atomic Structure {#introduction}

Historical Background

- **Dalton's Theory:** Atoms were considered indivisible and indestructible
- **19th Century Challenge:** Scientists needed to understand atomic structure and properties
- **Key Questions:**
 1. What makes atoms of different elements different?

2. Are atoms really indivisible?

Discovery Timeline

1886 → E. Goldstein discovers canal rays (protons)

1897 → J.J. Thomson discovers electrons

1911 → Rutherford's gold foil experiment

1913 → Bohr's atomic model

1932 → J. Chadwick discovers neutrons

2. Discovery of Sub-atomic Particles {#subatomic}

2.1 Charged Particles in Matter

Evidence of Charged Particles:

Activity 4.1 Observations:

- Combing dry hair attracts paper pieces
- Rubbed glass rod affects balloon
- **Conclusion:** Objects become electrically charged when rubbed

2.2 Discovery of Electron

- **Discovered by:** J.J. Thomson
- **Method:** Cathode ray tube experiments
- **Properties:**
 - Negatively charged
 - Symbol: e^-

- Mass: Negligible (1/2000 times proton mass)
- Charge: -1 unit

2.3 Discovery of Proton

- **Discovered by:** E. Goldstein (1886)
- **Method:** Canal rays experiment
- **Properties:**
 - Positively charged
 - Symbol: p^+
 - Mass: 1 unit (approximately)
 - Charge: +1 unit

2.4 Discovery of Neutron

- **Discovered by:** J. Chadwick (1932)
- **Properties:**
 - Electrically neutral
 - Symbol: n
 - Mass: 1 unit (nearly equal to proton)
 - Charge: 0

Comparison of Sub-atomic Particles:

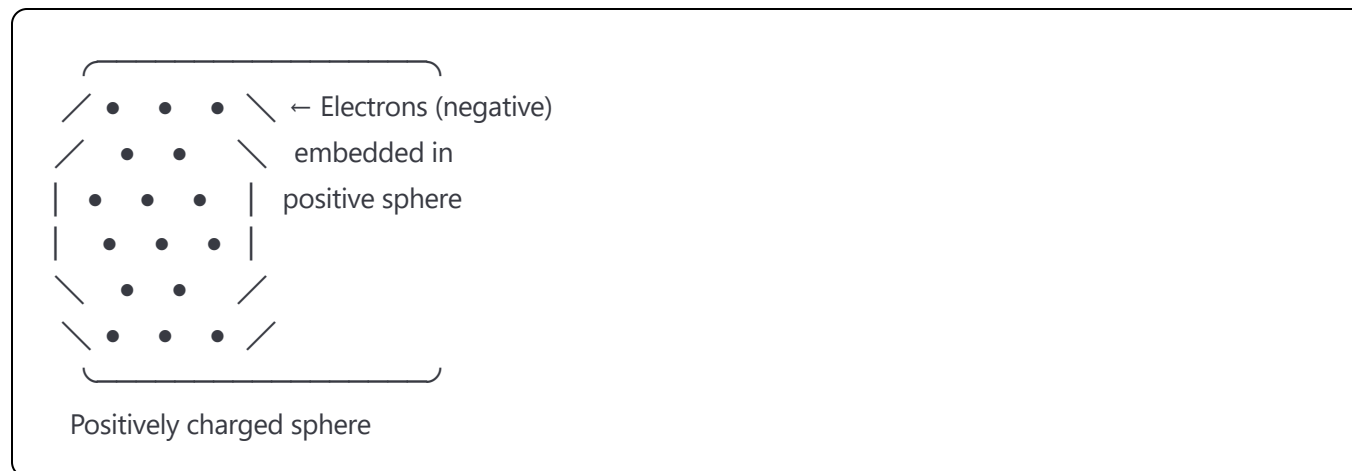
Particle	Symbol	Charge	Mass (u)	Location	Discoverer
Electron	e^-	-1	~ 0 (1/2000)	Outside nucleus	J.J. Thomson
Proton	p^+	+1	1	Nucleus	E. Goldstein
Neutron	n	0	1	Nucleus	J. Chadwick

3. Thomson's Atomic Model (1904) {#thomson}

Key Features:

1. **Structure:** Atom is like a Christmas pudding or watermelon
2. **Positive charge:** Spread throughout the atom like pudding
3. **Electrons:** Embedded in positive sphere like dry fruits in pudding
4. **Overall charge:** Neutral (positive and negative charges balance)

Diagram: Thomson's Model



Merits:

- Explained electrical neutrality of atoms
- First model to include sub-atomic particles

Limitations:

- Could not explain results of later experiments
- No explanation for atomic stability

- Failed to explain Rutherford's gold foil experiment results

4. Rutherford's Atomic Model (1911) {#rutherford}

4.1 The Gold Foil Experiment

Experimental Setup:

- **Source:** Fast-moving α -particles (doubly charged helium ions, mass = 4u)
- **Target:** Thin gold foil (1000 atoms thick)
- **Detector:** Zinc sulphide screen
- **Expectation:** Small deflections due to electron interactions

Observations:

1. **Most α -particles:** Passed straight through (99.9%)
2. **Some α -particles:** Deflected by small angles
3. **Very few α -particles:** Deflected by large angles (1 in 12,000 rebounded)

Diagram: Rutherford's Experiment

α -particle $\rightarrow \rightarrow \rightarrow \rightarrow$ | Gold Foil | $\rightarrow \rightarrow \rightarrow$ Most pass through
 source ↗ | | ↗ Some deflect
 ↗ | • | ↗ Few rebound
 ← | nucleus | ←
 | |
 Detector screen surrounds the setup

4.2 Conclusions from Experiment:

Rutherford's Reasoning:

Analogy: Like throwing stones at a barbed wire fence

- Most stones pass through gaps (most α -particles pass through)
- Few hit wires and deflect (few α -particles deflect)

Scientific Conclusions:

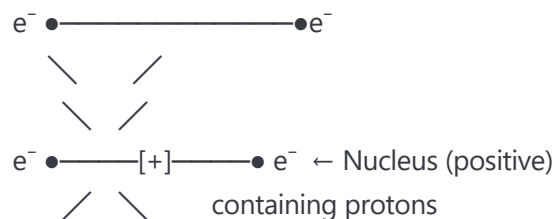
1. **Most space is empty:** Most α -particles passed through
2. **Positive charge concentrated:** Very small volume causes large deflections
3. **Nucleus exists:** All positive charge and mass concentrated in tiny center
4. **Size calculation:** Nucleus radius $\approx 10^{-5}$ times atomic radius

4.3 Rutherford's Nuclear Model:

Features:

1. **Nucleus:** Positively charged center containing all mass
2. **Electrons:** Revolve around nucleus in circular orbits
3. **Size:** Nucleus very small compared to atom
4. **Empty space:** Most of atom is empty

Diagram: Rutherford's Model





Electrons revolving in circular orbits

4.4 Limitations of Rutherford's Model:

1. **Stability problem:** Revolving electrons should lose energy and spiral into nucleus
 2. **Radiation issue:** Accelerating charges should radiate energy
 3. **Atom collapse:** According to classical physics, atoms should collapse
-

5. Bohr's Atomic Model (1913) {#bohr}

5.1 Bohr's Postulates:

Main Postulates:

1. **Discrete orbits:** Only certain special orbits are allowed for electrons
2. **No energy radiation:** Electrons in these orbits do not radiate energy
3. **Energy levels:** Each orbit has definite energy (stationary states)
4. **Energy changes:** Energy absorbed/emitted only when electron jumps between orbits

5.2 Features of Bohr's Model:

- **Shells/Energy levels:** K, L, M, N... or $n = 1, 2, 3, 4...$
- **Stable electrons:** In allowed orbits without energy loss
- **Quantum concept:** Introduced quantum theory to atomic structure

Diagram: Bohr's Model



5.3 Merits of Bohr's Model:

- Explained atomic stability
- Successfully explained hydrogen spectrum
- Introduced concept of energy levels
- Foundation for modern atomic theory

5.4 Limitations:

- Could not explain spectra of multi-electron atoms
 - Did not explain chemical bonding completely
 - Failed to explain Zeeman and Stark effects
-

6. Electronic Configuration {#electronic}

6.1 Rules for Electron Distribution (Bohr-Bury Scheme):

Rule 1: Maximum Electrons per Shell

Formula: Maximum electrons = $2n^2$

- **K shell (n=1):** $2 \times 1^2 = 2$ electrons
- **L shell (n=2):** $2 \times 2^2 = 8$ electrons
- **M shell (n=3):** $2 \times 3^2 = 18$ electrons
- **N shell (n=4):** $2 \times 4^2 = 32$ electrons

Rule 2: Outermost Shell Limit

- Maximum 8 electrons in outermost shell (except K shell which can have max 2)

Rule 3: Step-wise Filling

- Inner shells must be filled before outer shells
- Electrons fill shells in order: $K \rightarrow L \rightarrow M \rightarrow N$

6.2 Electronic Configuration of First 18 Elements:

Element	Symbol	Atomic No.	K	L	M	N	Configuration
Hydrogen	H	1	1	-	-	-	1
Helium	He	2	2	-	-	-	2
Lithium	Li	3	2	1	-	-	2,1
Beryllium	Be	4	2	2	-	-	2,2
Boron	B	5	2	3	-	-	2,3
Carbon	C	6	2	4	-	-	2,4

Element	Symbol	Atomic No.	K	L	M	N	Configuration
Nitrogen	N	7	2	5	-	-	2,5
Oxygen	O	8	2	6	-	-	2,6
Fluorine	F	9	2	7	-	-	2,7
Neon	Ne	10	2	8	-	-	2,8
Sodium	Na	11	2	8	1	-	2,8,1
Magnesium	Mg	12	2	8	2	-	2,8,2
Aluminium	Al	13	2	8	3	-	2,8,3
Silicon	Si	14	2	8	4	-	2,8,4
Phosphorus	P	15	2	8	5	-	2,8,5
Sulphur	S	16	2	8	6	-	2,8,6
Chlorine	Cl	17	2	8	7	-	2,8,7
Argon	Ar	18	2	8	8	-	2,8,8

Diagram: Electronic Configuration Examples

Carbon (2,4):	Sodium (2,8,1):
2e ⁻	2e ⁻
K: ●●	K: ●●
L: ●●●●	L: ●●●●●●●●
	M: ●

7. Valency {#valency}

7.1 Definition:

Valency is the combining capacity of an atom, determined by the number of electrons in the

outermost shell.

7.2 Determination of Valency:

Method 1: For elements with 1-4 outer electrons

Valency = Number of outer electrons

- Na (2,8,1) → Valency = 1
- Mg (2,8,2) → Valency = 2
- Al (2,8,3) → Valency = 3

Method 2: For elements with 5-7 outer electrons

Valency = 8 - Number of outer electrons

- F (2,7) → Valency = $8-7 = 1$
- O (2,6) → Valency = $8-6 = 2$
- N (2,5) → Valency = $8-5 = 3$

Method 3: For noble gases

Valency = 0 (complete outer shell)

- He (2) → Valency = 0
- Ne (2,8) → Valency = 0
- Ar (2,8,8) → Valency = 0

7.3 Octet Rule:

- **Definition:** Atoms tend to achieve 8 electrons in outermost shell
- **Exception:** Hydrogen and Helium follow duplet rule (2 electrons)

- **Methods to achieve octet:**
 1. **Gaining electrons** (non-metals)
 2. **Losing electrons** (metals)
 3. **Sharing electrons** (covalent bonding)

Valency Table for First 18 Elements:

Element	Outer Electrons	Valency	Reasoning
H	1	1	Lose 1 or gain 1
He	2	0	Complete duplet
Li	1	1	Lose 1
Be	2	2	Lose 2
B	3	3	Lose 3
C	4	4	Share 4
N	5	3	Gain 3 (8-5)
O	6	2	Gain 2 (8-6)
F	7	1	Gain 1 (8-7)
Ne	8	0	Complete octet

8. Atomic Number and Mass Number {#atomic-mass}

8.1 Atomic Number (Z):

- **Definition:** Number of protons in the nucleus
- **Symbol:** Z
- **Characteristics:**
 - Unique for each element

- Determines element's identity
- Equal to number of electrons in neutral atom

8.2 Mass Number (A):

- **Definition:** Sum of protons and neutrons in nucleus
- **Symbol:** A
- **Formula:** $A = \text{Number of protons} + \text{Number of neutrons}$
- **Also called:** Nucleon number

8.3 Standard Notation:

$$\begin{matrix} A \\ Z X \end{matrix}$$

Where: A = Mass number

Z = Atomic number

X = Element symbol

Examples:

- **Carbon:** ${}_{12}\text{C}_6$ (12 mass number, 6 atomic number)
- **Nitrogen:** ${}_{14}\text{N}_7$ (14 mass number, 7 atomic number)
- **Oxygen:** ${}_{16}\text{O}_8$ (16 mass number, 8 atomic number)

8.4 Relationship Between Particles:

- **In neutral atom:** Number of protons = Number of electrons
- **Mass calculation:** $\text{Mass} \approx \text{Protons} + \text{Neutrons}$
- **Neutrons:** $A - Z$ (Mass number - Atomic number)

Calculation Examples:

Example 1: Carbon-12

- Atomic number (Z) = 6
- Mass number (A) = 12
- Protons = 6, Electrons = 6
- Neutrons = $12 - 6 = 6$

Example 2: Aluminium-27

- Atomic number (Z) = 13
 - Mass number (A) = 27
 - Protons = 13, Electrons = 13
 - Neutrons = $27 - 13 = 14$
-

9. Isotopes and Isobars {#isotopes}

9.1 Isotopes:

Definition:

Isotopes are atoms of the same element having same atomic number but different mass numbers.

Characteristics:

- Same number of protons
- Different number of neutrons
- Same chemical properties
- Different physical properties

Examples:

Hydrogen Isotopes:

1. **Protium:** ${}_1\text{H}_1$ (1 proton, 0 neutrons)
2. **Deuterium:** ${}_2\text{H}_1$ or D (1 proton, 1 neutron)
3. **Tritium:** ${}_3\text{H}_1$ or T (1 proton, 2 neutrons)

Carbon Isotopes:

- **Carbon-12:** ${}_{12}\text{C}_6$ (6 protons, 6 neutrons)
- **Carbon-14:** ${}_{14}\text{C}_6$ (6 protons, 8 neutrons)

Chlorine Isotopes:

- **Chlorine-35:** ${}_{35}\text{Cl}_{17}$ (17 protons, 18 neutrons)
- **Chlorine-37:** ${}_{37}\text{Cl}_{17}$ (17 protons, 20 neutrons)

Diagram: Isotopes of Hydrogen

Protium (${}_1\text{H}_1$): Deuterium (${}_2\text{H}_1$): Tritium (${}_3\text{H}_1$):

[p⁺]



e⁻

[p⁺n]



e⁻

[p⁺n n]



e⁻

9.2 Average Atomic Mass:

Calculation Method:

When an element has isotopes, average atomic mass is calculated using:

$$\text{Average atomic mass} = \Sigma(\text{Isotope mass} \times \% \text{ abundance})/100$$

Example: Chlorine

- Cl-35: 75% abundance, mass = 35u
- Cl-37: 25% abundance, mass = 37u
- Average mass = $(35 \times 75 + 37 \times 25)/100 = (2625 + 925)/100 = 35.5\text{u}$

9.3 Applications of Isotopes:

1. **Uranium isotope:** Nuclear fuel in reactors
2. **Cobalt isotope:** Cancer treatment
3. **Iodine isotope:** Goitre treatment
4. **Carbon-14:** Radioactive dating
5. **Deuterium:** Heavy water in nuclear reactors

9.4 Isobars:

Definition:

Isobars are atoms of different elements having same mass number but different atomic numbers.

Characteristics:

- Different number of protons
- Different number of electrons
- Different chemical properties
- Same mass number

Examples:

- **Calcium-40:** ${}_{20}\text{Ca}_{20}$ (20 protons, 20 neutrons)
- **Argon-40:** ${}_{18}\text{Ar}_{22}$ (18 protons, 22 neutrons)

Comparison: Isotopes vs Isobars

Property	Isotopes	Isobars
Atomic number	Same	Different
Mass number	Different	Same
Chemical properties	Same	Different
Physical properties	Different	May be different
Examples	C-12, C-14	Ca-40, Ar-40

10. Detailed Diagrams for Understanding

10.1 Evolution of Atomic Models:

Thomson (1904)

••••••••••

Positive sphere
with embedded
electrons

→

Rutherford (1911)

e⁻

[+]

e⁻

e⁻

|

e⁻

•

→

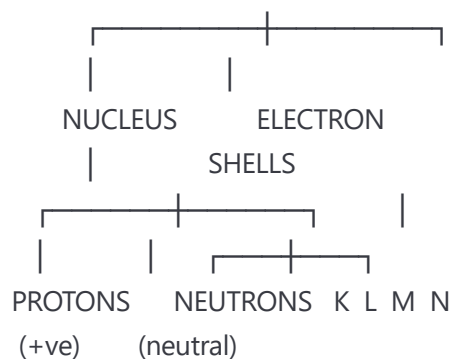
Bohr (1913)

Energy levels
with electrons
in fixed orbits

10.2 Sub-atomic Particle Arrangement:

ATOM

|



10.3 Shell Filling Diagram:

K shell: ●● (max 2)

L shell: ●●●●●●●● (max 8)

M shell: ●●●●●●●●●●●●●●●● (max 18)

N shell: ●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●● (max 32)

11. Important Formulas and Calculations

11.1 Key Formulas:

1. **Maximum electrons in shell:** $2n^2$
2. **Number of neutrons:** Mass number - Atomic number
3. **Average atomic mass:** $\Sigma(\text{Isotope mass} \times \% \text{ abundance})/100$
4. **Valency calculation:**
 - If outer electrons ≤ 4 : Valency = outer electrons
 - If outer electrons > 4 : Valency = $8 - \text{outer electrons}$

11.2 Solved Examples:

Example 1: Electronic Configuration

Problem: Write electronic configuration of Chlorine ($Z = 17$) **Solution:**

- Total electrons = 17
- K shell = 2 electrons
- L shell = 8 electrons
- M shell = 7 electrons
- Configuration: 2, 8, 7

Example 2: Neutron Calculation

Problem: Find neutrons in Aluminium-27 **Solution:**

- Mass number (A) = 27
- Atomic number (Z) = 13
- Neutrons = $A - Z = 27 - 13 = 14$

Example 3: Average Atomic Mass

Problem: Bromine has isotopes ^{79}Br (49.7%) and ^{81}Br (50.3%). Calculate average atomic mass.

Solution:

- Average mass = $(79 \times 49.7 + 81 \times 50.3)/100$
- = $(3926.3 + 4074.3)/100$
- = $8000.6/100 = 80.006\text{u} \approx 80\text{u}$

12. Exam-Style Questions and Answers

Very Short Answer Questions (1 Mark):

Q1: Who discovered neutron? **A1:** J. Chadwick

Q2: What is the maximum number of electrons in L shell? **A2:** 8 electrons

Q3: Write the electronic configuration of sodium. **A3:** 2, 8, 1

Q4: Define atomic number. **A4:** Number of protons in the nucleus of an atom

Q5: What are canal rays? **A5:** Positively charged radiations discovered by Goldstein

Short Answer Questions (2-3 Marks):

Q6: State the postulates of Bohr's atomic model. **A6:**

1. Electrons revolve in fixed orbits called energy levels
2. Electrons in these orbits do not radiate energy
3. Energy is absorbed/emitted when electrons jump between orbits

Q7: Why is Rutherford's model called nuclear model? **A7:**

- Rutherford discovered nucleus at center of atom
- All positive charge and mass concentrated in nucleus
- Electrons revolve around this central nucleus
- Hence called nuclear model

Q8: Calculate valency of nitrogen and fluorine. **A8:**

- **Nitrogen:** Electronic configuration = 2,5; Valency = $8-5 = 3$
- **Fluorine:** Electronic configuration = 2,7; Valency = $8-7 = 1$

Long Answer Questions (5 Marks):

Q9: Describe Rutherford's α -particle scattering experiment and its conclusions. **A9: Experiment:**

- Fast-moving α -particles directed at thin gold foil
- Expected small deflections due to Thomson's model

Observations:

1. Most α -particles passed straight through
2. Some deflected by small angles
3. Very few (1 in 12,000) bounced back

Conclusions:

1. Most of atom is empty space
2. Positive charge concentrated in small nucleus
3. Nucleus contains all mass of atom
4. Nucleus size $\ll$ atomic size

Q10: Compare Thomson's and Rutherford's atomic models. **A10:**

Aspect	Thomson's Model	Rutherford's Model
Structure	Positive sphere with embedded electrons	Nucleus with orbiting electrons
Charge distribution	Uniformly distributed	Concentrated in nucleus
Space	Completely filled	Mostly empty
Electron arrangement	Embedded randomly	Revolving in orbits
Stability	Assumed stable	Could not explain stability

13. Common Exam Patterns and Important Points

13.1 High-Weightage Topics:

1. **Electronic configuration** of first 18 elements
2. **Rutherford's experiment** and conclusions
3. **Isotopes and their applications**
4. **Valency calculations**
5. **Atomic number vs mass number**
6. **Comparison of atomic models**

13.2 Numerical Problems Types:

1. Electronic configuration writing
2. Valency determination
3. Neutron calculation
4. Average atomic mass calculation
5. Isotope and isobar identification

13.3 Diagram-Based Questions:

- Draw atomic models
 - Show electronic configuration
 - Rutherford's experimental setup
 - Isotope representation
-

14. Key Points for Quick Revision

14.1 Sub-atomic Particles:

- **Electron:** e^- , mass ≈ 0 , charge = -1
- **Proton:** p^+ , mass = 1u, charge = +1
- **Neutron:** n, mass = 1u, charge = 0

14.2 Atomic Models Summary:

- **Thomson:** Plum pudding model
- **Rutherford:** Nuclear model with orbiting electrons
- **Bohr:** Quantized energy levels

14.3 Electronic Rules:

- K shell: max 2 electrons
- L shell: max 8 electrons
- M shell: max 18 electrons
- Outermost shell: max 8 electrons

14.4 Important Scientists:

- **J.J. Thomson:** Electron discovery, plum pudding model
 - **E. Goldstein:** Canal rays (protons)
 - **E. Rutherford:** Nuclear model, gold foil experiment
 - **N. Bohr:** Quantum model, energy levels
 - **J. Chadwick:** Neutron discovery
-

15. Memory Techniques and Mnemonics

15.1 For Electronic Configuration:

"King Louis Made Napoleon" → K, L, M, N shells

15.2 For Valency Calculation:

"Less than 4 - Direct, More than 4 - Subtract from 8"

15.3 For Atomic Models:

"Tom Ran Backwards" → Thomson → Rutherford → Bohr

15.4 For Sub-atomic Particles:

"Electron Proton Neutron" → "Every Physicist Needs"

16. Common Mistakes to Avoid

1. **Don't confuse** atomic number with mass number
 2. **Remember** neutrons = mass number - atomic number
 3. **Electronic configuration:** Fill inner shells first
 4. **Valency:** Use correct method based on outer electrons
 5. **Isotopes:** Same element, different mass
 6. **Isobars:** Different elements, same mass
 7. **Noble gases:** Valency is always zero
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17. Practical Applications and Modern Relevance

17.1 Nuclear Technology:

- Nuclear power plants use uranium isotopes
- Medical isotopes for diagnosis and treatment
- Carbon dating using C-14

17.2 Electronic Devices:

- Understanding of electron behavior
- Semiconductor technology
- Electronic circuits and devices

17.3 Chemical Industry:

- Valency helps predict chemical bonding
 - Compound formation and reactions
 - Material science applications
-

18. Board Exam Strategy

18.1 Important Question Types:

1. **3-mark questions:** Model comparisons, experiment descriptions
2. **5-mark questions:** Complete experiment explanations, detailed model features
3. **Numerical problems:** Electronic configuration, valency, isotope calculations

18.2 Marking Scheme Tips:

- Always write complete electronic configuration
- Include proper symbols and notation
- Show all calculation steps
- Draw neat and labeled diagrams
- Mention scientist names with discoveries

18.3 Time Management:

- **Numerical problems:** 2-3 minutes each
 - **Short answers:** 3-4 minutes each
 - **Long answers:** 7-8 minutes each
 - **Diagram questions:** Always include labels
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19. Advanced Concepts (For Better Understanding)

19.1 Why Atoms are Stable:

- Bohr's quantized orbits prevent energy radiation
- Electron-proton attraction balanced by centrifugal force
- Nuclear forces hold nucleus together

19.2 Modern Atomic Theory:

- Electrons exist in probability clouds (orbitals)
- Quantum mechanical model replaces Bohr's model
- Wave-particle duality of electrons

19.3 Periodic Trends:

- Atomic size decreases across period
- Valency first increases then decreases across period
- Noble gases are most stable due to complete octets

Remember: Focus on understanding concepts rather than memorization. Practice numerical problems regularly and always relate atomic structure to chemical behavior for complete understanding!