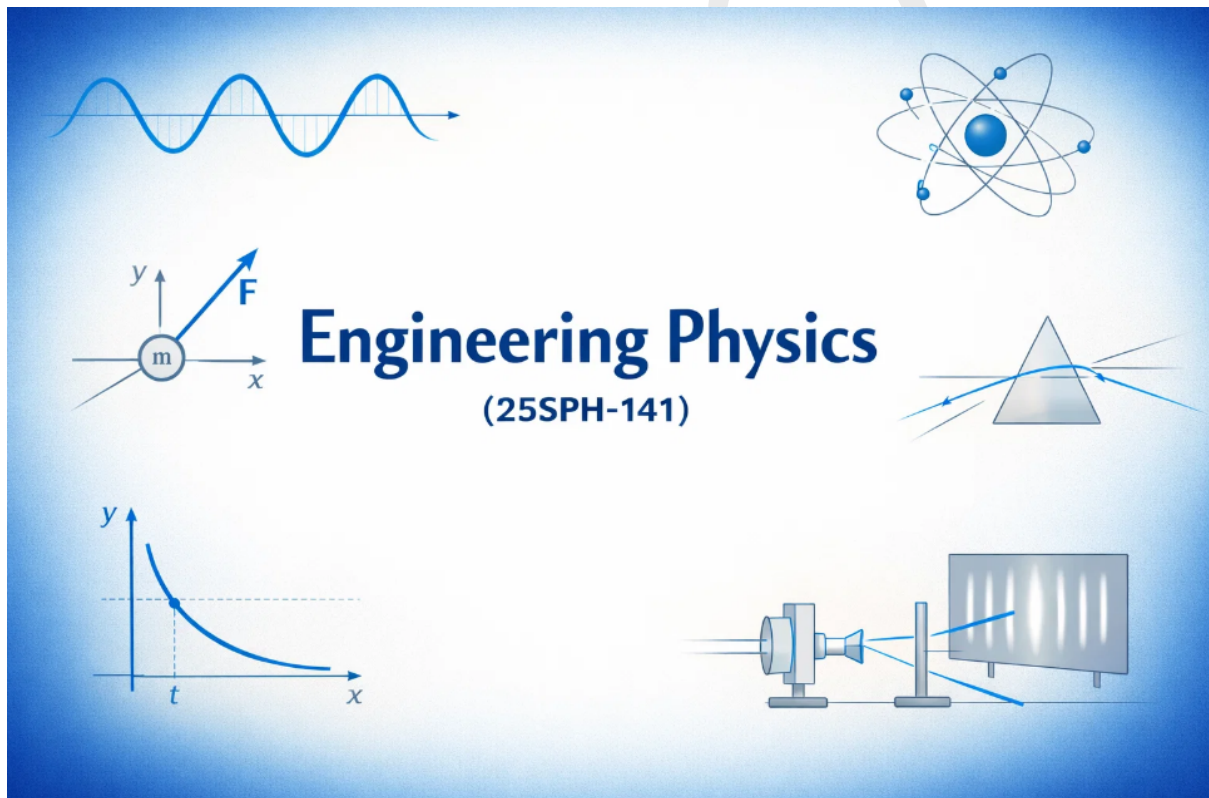


# Engineering Physics (25SPH-141)

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## Syllabus for Unit 1

### Engineering Physics (25SPH-141)

**Chapter 1 : Quantum Physics & Nanotechnology** - Quantum Theory (only postulates), Heisenberg's Uncertainty Principle, Wave-Particle Duality, de-Broglie Matter Waves, Wave Packet, Wave Function

Introduction to Nanotechnology, Quantum Confinement Effect, Classification of Nanomaterials, Methods of Synthesis-Top down and Bottom-up Approach: Ball Milling & Sol-Gel Method.

#### **Chapter 2 : Recent Inventions -**

1. Quantum Computing - Weather Forecasting, Cryptography
2. Edge Computing - IoT, Driverless Cars, and Healthcare
3. Carbon Nanomaterials - Carbon-based Nano Additives
4. Semiconductor Nanodevices - Nanomanipulators, and Nano-transistors
5. Green Nanotechnology - Bioremediation and Biotransformation of soil, Wastewater, Oil Spills, and Other Toxic Pollutants
6. Nanocomposites for Coatings, Additives, Catalysts, and Structural Components
7. Nano-sensors - Enabling Contamination Detection, Environmental Measurements, Remote Sensing, and Communication
8. Nanoencapsulation for Drug Delivery, Bioimaging, Theragnosis, Immunization
9. Nanomaterials for Water Treatment
10. Nanotechnology for Energy Harvesting - Electrodes, and Solar Cells

# Chapter 1

## Quantum Physics & Nanotechnology

Quantum Physics forms the foundation of modern physics and explains the behavior of matter and energy at atomic and subatomic scales. Classical physics fails to describe phenomena at very small dimensions, where quantum effects dominate. This chapter introduces the fundamental ideas of quantum theory through its postulates, Heisenberg's Uncertainty Principle, and the concept of wave-particle duality.

### 1.1 Quantum Theory (Postulates Only)

Quantum theory is based on a set of fundamental postulates that describe the behavior of microscopic systems such as electrons, atoms, and photons.

#### Postulate 1: Quantization of Physical Quantities

Certain physical quantities, such as energy, are not continuous but occur in discrete values called **quanta**.

For an electron bound in an atom, energy can take only specific allowed values:

$$E = E_1, E_2, E_3, \dots$$

This explains why atoms emit or absorb radiation only at specific frequencies.

#### Postulate 2: Wave Function and Probability Interpretation

The state of a quantum system is completely described by a wave function  $\psi(x, t)$ .

The quantity  $|\psi(x, t)|^2$  represents the **probability density** of finding the particle at position  $x$  at time  $t$ .

$$|\psi|^2 = \text{Probability density}$$



The wave function itself has no direct physical meaning.

### Postulate 3: Expectation Value of an Observable

Every measurable physical quantity (observable) is represented by an operator.

The expectation value of an observable  $A$  is given by:

$$\langle A \rangle = \int \psi^* \hat{A} \psi d\tau$$

This represents the average value of the observable over many measurements.

### Postulate 4: Measurement and Wave Function Collapse

When a measurement is performed, the wave function collapses to one of the eigenstates corresponding to the measured value.

After measurement, the system no longer remains in a superposition of states.

### Postulate 5: Time Evolution of the Wave Function

The time evolution of a quantum system is governed by the Schrödinger equation.

This equation determines how the wave function changes with time.

## 1.2 Heisenberg's Uncertainty Principle

Heisenberg's Uncertainty Principle states that it is impossible to simultaneously measure certain pairs of physical quantities with absolute precision.

For position and momentum:

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

where:

- $\Delta x$  = uncertainty in position
- $\Delta p$  = uncertainty in momentum
- $\hbar = \frac{h}{2\pi}$

### Physical Significance

The uncertainty principle is not due to experimental limitations but is a fundamental property of nature.

At microscopic scales:



- Exact particle trajectories do not exist
- Increasing accuracy in position measurement increases uncertainty in momentum

## Consequences

- Explains stability of atoms
- Rules out classical deterministic motion for electrons
- Important in nanotechnology and quantum devices

## 1.3 Wave–Particle Duality

Wave–particle duality states that microscopic entities such as electrons and photons exhibit both wave-like and particle-like behavior.

### Dual Nature of Light

Light behaves as:

- A wave (interference and diffraction)
- A particle (photoelectric effect)

The particle nature of light is explained by photons, each having energy:

$$E = h\nu$$

### Dual Nature of Matter

Louis de Broglie proposed that matter particles also possess wave nature.

The de Broglie wavelength is given by:

$$\lambda = \frac{h}{p}$$

where  $p$  is the momentum of the particle.

This concept was experimentally verified by electron diffraction experiments.

### Importance of Wave–Particle Duality

- Explains atomic structure
- Forms the basis of quantum mechanics
- Essential for understanding nanoscale phenomena



## Chapter Summary

This chapter introduced the foundational principles of quantum physics through the postulates of quantum theory, Heisenberg's Uncertainty Principle, and wave-particle duality. These concepts explain the limitations of classical physics and form the theoretical basis for modern technologies such as semiconductors, nanodevices, and quantum computing.

### 1.4 de Broglie Matter Waves

Louis de Broglie proposed that not only radiation but also material particles exhibit wave-like properties. This idea unified the concepts of particles and waves under a single framework.

According to de Broglie, every moving particle of momentum  $p$  is associated with a wave whose wavelength is given by:

$$\lambda = \frac{h}{p}$$

where:

- $\lambda$  = de Broglie wavelength
- $h$  = Planck's constant
- $p = mv$  = momentum of the particle

For a non-relativistic particle:

$$\lambda = \frac{h}{mv}$$

#### Physical Interpretation

The de Broglie wavelength represents the wave nature of a particle. It becomes significant only when the wavelength is comparable to atomic dimensions.

- For macroscopic objects,  $\lambda$  is extremely small and unobservable
- For electrons and subatomic particles,  $\lambda$  is appreciable

This concept explains phenomena such as electron diffraction and forms the basis of wave mechanics.

#### Experimental Verification

The wave nature of matter was experimentally verified by:

- Davisson-Germer experiment (electron diffraction)



- G. P. Thomson experiment

These experiments confirmed that electrons produce diffraction patterns similar to waves.

## Solved Numerical 1

**Problem:** Calculate the de Broglie wavelength of an electron moving with a velocity of  $1 \times 10^6$  m/s. (Given:  $h = 6.626 \times 10^{-34}$  J·s,  $m_e = 9.1 \times 10^{-31}$  kg)

**Solution:**

$$\lambda = \frac{h}{mv}$$

$$\lambda = \frac{6.626 \times 10^{-34}}{9.1 \times 10^{-31} \times 1 \times 10^6}$$

$$\lambda = 7.28 \times 10^{-10} \text{ m}$$

**Answer:** The de Broglie wavelength of the electron is  $7.28 \times 10^{-10}$  m.

## 1.5 Wave Packet

A **wave packet** is a group of waves with slightly different wavelengths and frequencies superimposed to form a localized wave.

In quantum mechanics:

- A single wave extends infinitely in space
- A wave packet represents a localized particle

### Need for Wave Packet

A particle must be localized in space. However:

- A monochromatic wave has infinite extent
- Superposition of waves forms a localized packet

Thus, a wave packet provides a realistic description of a moving particle.



## Group Velocity

The velocity with which a wave packet moves is called the **group velocity**.

$$v_g = \frac{d\omega}{dk}$$

For matter waves, the group velocity equals the particle velocity:

$$v_g = v$$

## Relation to Uncertainty Principle

Wave packets naturally lead to uncertainty:

- Narrow packet  $\Rightarrow$  well-defined position, uncertain momentum
- Broad packet  $\Rightarrow$  well-defined momentum, uncertain position

This directly supports Heisenberg's Uncertainty Principle.

## 1.6 Wave Function

The wave function  $\psi(x, t)$  is a fundamental concept in quantum mechanics that describes the state of a particle.

### Physical Meaning of Wave Function

The wave function itself has no direct physical meaning. Its square modulus represents probability density:

$$|\psi(x, t)|^2 = \text{Probability density}$$

Thus:

$$|\psi(x, t)|^2 dx = \text{Probability of finding the particle between } x \text{ and } x + dx$$

### Properties of an Acceptable Wave Function

A physically meaningful wave function must:

- Be finite everywhere
- Be single-valued
- Be continuous
- Be square integrable



## Normalization of Wave Function

Since a particle must exist somewhere in space, the total probability must be unity:

$$\int_{-\infty}^{+\infty} |\psi|^2 dx = 1$$

This condition is known as normalization.

### Solved Numerical 2

**Problem:** If a wave function is given by  $\psi = Ae^{-x^2}$ , find the probability density.

**Solution:**

$$|\psi|^2 = \psi^* \psi$$

$$|\psi|^2 = A^2 e^{-2x^2}$$

**Answer:** The probability density is  $A^2 e^{-2x^2}$ .

### Solved Numerical 3

**Problem:** If  $|\psi|^2 = 4x^2$ , find the probability density at  $x = 1$ .

**Solution:**

$$|\psi|^2 = 4(1)^2 = 4$$

**Answer:** The probability density at  $x = 1$  is 4.



## 1.7 Nanotechnology

Nanotechnology deals with the study, design, and application of materials and devices whose dimensions lie in the nanometer range. At this scale, materials exhibit unique physical, chemical, and electronic properties that are significantly different from their bulk counterparts.

## 1.8 Introduction to Nanotechnology

The term **nanotechnology** is derived from the Greek word *nanos*, meaning one billionth. A nanometer (nm) is equal to:

$$1 \text{ nm} = 10^{-9} \text{ m}$$

Nanotechnology focuses on materials whose at least one dimension lies between 1 nm and 100 nm.

### Why Nanotechnology is Important

At the nanoscale:

- Surface-to-volume ratio increases drastically
- Quantum mechanical effects become dominant
- Material properties change significantly

These effects enable the development of advanced materials with enhanced strength, conductivity, reactivity, and optical properties.

### Applications of Nanotechnology

- Electronics: Nano-transistors, quantum dots
- Medicine: Targeted drug delivery, imaging
- Energy: Solar cells, fuel cells
- Materials science: Nanocomposites, coatings

## 1.9 Quantum Confinement Effect

The **Quantum Confinement Effect** occurs when the dimensions of a material become comparable to the de Broglie wavelength of charge carriers such as electrons.

When a particle is confined to a very small region of space:



- Energy levels become discrete
- Band gap increases
- Optical and electrical properties change

## Origin of Quantum Confinement

In bulk materials, electrons can move freely and energy levels form continuous bands. In nanomaterials, confinement restricts electron motion, leading to quantized energy levels similar to a particle in a box.

## Effects of Quantum Confinement

- Shift in absorption and emission spectra
- Size-dependent optical properties
- Enhanced electrical and optical tunability

**Example:** Quantum dots emit different colors depending on their size, not their material composition.

## Technological Importance

Quantum confinement is crucial in:

- Quantum dots
- Nano-electronic devices
- Optoelectronic applications

## 1.10 Classification of Nanomaterials

Nanomaterials can be classified based on their dimensionality, which refers to the number of dimensions confined within the nanoscale.

### Zero-Dimensional (0D) Nanomaterials

All three dimensions are confined within the nanoscale.

**Examples:**

- Quantum dots



- Nanoparticles

**Properties:**

- Discrete energy levels
- Strong quantum confinement

## One-Dimensional (1D) Nanomaterials

Two dimensions are confined, while one dimension is extended.

**Examples:**

- Nanowires
- Nanorods
- Carbon nanotubes

**Properties:**

- High electrical conductivity along length
- Direction-dependent properties

## Two-Dimensional (2D) Nanomaterials

One dimension is confined, while two dimensions are extended.

**Examples:**

- Graphene
- Thin films
- Nanosheets

**Properties:**

- High surface area
- Excellent mechanical and electrical properties



## Three-Dimensional (3D) Nanomaterials

Nanostructures extend in all three dimensions but contain nanoscale features.

### Examples:

- Nanocomposites
- Nanocrystalline solids

### Properties:

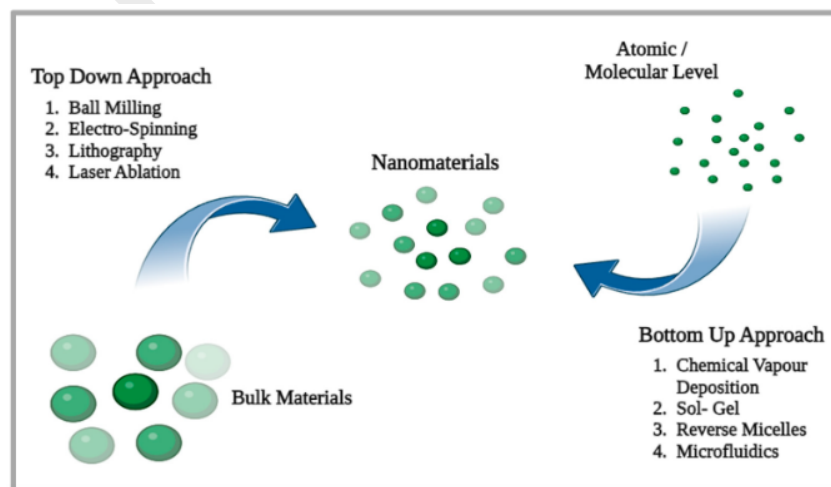
- Enhanced strength
- Improved thermal and electrical behavior

## Summary

This part introduced nanotechnology, explained the quantum confinement effect, and classified nanomaterials based on dimensionality. These concepts highlight how nanoscale dimensions fundamentally alter material behavior, enabling advanced technological applications.

### 1.11 Methods of Synthesis of Nanomaterials

Nanomaterials can be synthesized using two broad approaches based on how the material structure is formed: the **Top-Down approach** and the **Bottom-Up approach**. These methods differ in principle, technique, and applications.





### 1.11.1 Top-Down Approach

In the **Top-Down approach**, bulk materials are broken down into nanoscale structures using physical or mechanical methods.

**Key Characteristics:**

- Starts with bulk material
- Material size is reduced to the nanometer scale
- Commonly used in industrial processes

**Advantages:**

- Suitable for large-scale production
- Well-established and relatively simple techniques

**Limitations:**

- Introduces structural defects
- Limited control over particle size and shape

### Ball Milling Method

**Ball milling** is a mechanical top-down technique used to produce nanomaterials by grinding bulk materials into fine powders.

**Working Principle:** A rotating cylindrical container is filled with hardened steel or ceramic balls along with the bulk material. As the container rotates, the balls collide with the material, causing repeated fracturing and size reduction.

**Process Description:**

- Bulk material and balls are placed inside a milling chamber
- High-energy collisions occur due to rotation
- Particle size reduces gradually to nanoscale

**Applications:**

- Production of metal and alloy nanoparticles
- Preparation of nanocomposites

**Advantages:**

- Simple and cost-effective



- Suitable for large quantities

**Disadvantages:**

- Contamination from milling media
- Poor control over particle morphology

### 1.11.2 Bottom-Up Approach

In the **Bottom-Up approach**, nanomaterials are built atom-by-atom or molecule-by-molecule through chemical or physical processes.

**Key Characteristics:**

- Starts from atoms or molecules
- Better control over size and structure
- Mimics natural material formation

**Advantages:**

- High purity nanomaterials
- Uniform particle size and shape

**Limitations:**

- More complex process
- Higher production cost

### Sol–Gel Method

The **Sol–Gel method** is a chemical bottom-up technique used to synthesize nanomaterials, especially metal oxides.

**Basic Principle:** The process involves the transition of a system from a liquid sol (colloidal suspension) into a solid gel phase.

**Steps Involved:**

- **Sol Formation:** Metal alkoxides or salts are dissolved to form a colloidal solution
- **Gelation:** Hydrolysis and condensation reactions form a three-dimensional network
- **Aging and Drying:** Removal of solvents strengthens the gel
- **Calcination:** Heat treatment removes residual organics and forms nanomaterials



**Applications:**

- Preparation of oxide nanoparticles
- Thin films and coatings
- Optical and electronic materials

**Advantages:**

- Excellent control over composition
- High purity and homogeneity

**Disadvantages:**

- Shrinkage during drying
- Long processing time

## Conclusion

The synthesis of nanomaterials using top-down and bottom-up approaches plays a crucial role in determining their properties and applications. While ball milling offers simplicity and scalability, sol-gel methods provide superior control and material quality. The choice of synthesis technique depends on the desired application and material characteristics.

## Extended Chapter Insight

The concepts of de Broglie matter waves, wave packets, and wave functions provide a complete quantum description of particles. Together, they replace classical trajectories with probability-based descriptions, forming the foundation for modern quantum physics and nanotechnology applications.

# Chapter 2

## Recent Inventions

Recent inventions driven by advances in physics, computing, and nanotechnology are transforming modern science, industry, and society. This chapter discusses key emerging technologies such as quantum computing, edge computing, carbon nanomaterials, semiconductor nanodevices, and green nanotechnology, along with their important applications.

### 2.1 Quantum Computing

Quantum computing is an advanced computing paradigm that uses principles of quantum mechanics such as superposition, entanglement, and quantum interference.

Unlike classical computers that use bits (0 or 1), quantum computers use **qubits**, which can exist in multiple states simultaneously.

#### Key Principles

- **Superposition:** A qubit can represent both 0 and 1 at the same time
- **Entanglement:** Qubits can be correlated such that the state of one affects another
- **Quantum Parallelism:** Enables faster computation for specific problems

#### 2.1.1 Applications of Quantum Computing

##### Weather Forecasting

Weather forecasting involves processing massive datasets and solving complex equations.

Quantum computing helps by:

- Performing faster simulations of atmospheric models
- Improving prediction accuracy



- Reducing computation time for climate modeling

## Cryptography

Quantum computers can significantly impact cryptography.

- Can break traditional encryption algorithms
- Enable quantum-safe cryptographic techniques
- Support secure quantum communication

## 2.2 Edge Computing

Edge computing is a distributed computing approach where data processing occurs close to the data source rather than a centralized cloud.

### Need for Edge Computing

- Reduces latency
- Minimizes bandwidth usage
- Enables real-time decision-making

### 2.2.1 Applications of Edge Computing

#### Internet of Things (IoT)

Edge computing allows IoT devices to:

- Process data locally
- Respond faster to sensor inputs
- Improve system efficiency

#### Driverless Cars

Autonomous vehicles require real-time processing.

Edge computing helps by:

- Enabling instant decision-making
- Reducing reliance on cloud connectivity
- Enhancing safety and reliability



## Healthcare

In healthcare systems, edge computing supports:

- Real-time patient monitoring
- Faster diagnosis
- Secure handling of sensitive medical data

## 2.3 Carbon Nanomaterials

Carbon nanomaterials are materials composed primarily of carbon atoms arranged at the nanoscale, exhibiting exceptional mechanical, electrical, and thermal properties.

### Types of Carbon Nanomaterials

- Carbon nanotubes
- Graphene
- Fullerenes

#### 2.3.1 Carbon-Based Nano Additives

Carbon-based nano additives are used to enhance material performance.

##### **Advantages:**

- Improved strength and durability
- Enhanced electrical conductivity
- Better thermal stability

##### **Applications:**

- Polymer composites
- Lubricants
- Energy storage devices

## 2.4 Semiconductor Nanodevices

Semiconductor nanodevices operate at nanometer dimensions and form the backbone of modern electronics.



## Nanomanipulators

Nanomanipulators are tools designed to manipulate objects at the nanoscale.

### Applications:

- Assembly of nanostructures
- Biomedical research
- Nanoelectronics fabrication

## Nano-Transistors

Nano-transistors are miniaturized transistors that enable high-speed and low-power electronic devices.

### Advantages:

- Increased processing speed
- Reduced power consumption
- Higher device density

## 2.5 Green Nanotechnology

Green nanotechnology focuses on the development of environmentally friendly nanomaterials and processes that reduce environmental impact.

### Bioremediation and Biotransformation

Nanotechnology plays a crucial role in environmental cleanup through bioremediation and biotransformation.

#### Applications include:

- Treatment of contaminated soil
- Purification of wastewater
- Cleanup of oil spills
- Removal of toxic pollutants

Nanomaterials enhance these processes by:

- Increasing reaction efficiency
- Accelerating pollutant degradation
- Reducing environmental toxicity



## Chapter Summary

This chapter explored recent inventions that are shaping modern technology, including quantum computing, edge computing, carbon nanomaterials, semiconductor nanodevices, and green nanotechnology. These advancements demonstrate the growing role of physics and nanoscience in addressing real-world challenges and driving future innovation.

## 2.6 Nanocomposites

Nanocomposites are advanced materials formed by embedding nanomaterials into a bulk matrix such as polymers, metals, or ceramics. The presence of nanoscale fillers significantly enhances the physical, chemical, and mechanical properties of the base material.

### Applications of Nanocomposites

#### Coatings:

- Improved corrosion resistance
- Enhanced wear and scratch resistance
- Self-cleaning and anti-fouling surfaces

#### Additives:

- Increased strength and durability
- Improved thermal and electrical properties
- Reduced material weight

#### Catalysts:

- High surface area for faster reactions
- Improved catalytic efficiency
- Reduced material usage

#### Structural Components:

- Aerospace and automotive parts
- Lightweight yet high-strength materials
- Enhanced fatigue resistance



## 2.7 Nano-Sensors

Nano-sensors are devices that use nanomaterials to detect physical, chemical, or biological changes with extremely high sensitivity.

### Working Principle

Due to their large surface-to-volume ratio, nanomaterials respond quickly to small changes in their environment, making them ideal for sensing applications.

### Applications of Nano-Sensors

- **Contamination Detection:** Detection of toxic gases, chemicals, and pathogens
- **Environmental Measurements:** Monitoring air and water quality
- **Remote Sensing:** Satellite and space-based environmental monitoring
- **Communication:** Signal detection and enhancement in communication systems

Nano-sensors enable rapid, accurate, and real-time monitoring.

## 2.8 Nanoencapsulation

Nanoencapsulation involves enclosing active substances within nanometer-sized carriers to protect and control their release.

### Advantages of Nanoencapsulation

- Controlled and targeted delivery
- Enhanced stability of active agents
- Reduced side effects

### Applications of Nanoencapsulation

#### Drug Delivery:

- Targeted delivery to specific tissues
- Improved bioavailability

#### Bioimaging:



- Enhanced contrast in medical imaging
- Early disease detection

**Theragnosis:**

- Combined therapy and diagnosis
- Personalized medical treatment

**Immunization:**

- Controlled vaccine delivery
- Improved immune response

## 2.9 Nanomaterials for Water Treatment

Nanotechnology offers effective solutions for water purification and wastewater treatment.

### Role of Nanomaterials

- Removal of heavy metals
- Elimination of microorganisms
- Degradation of organic pollutants

### Advantages

- High purification efficiency
- Low energy requirement
- Cost-effective treatment methods

Nanomaterials such as nanoparticles, nanotubes, and nanofibers are widely used in filtration and purification systems.

## 2.10 Nanotechnology for Energy Harvesting

Nanotechnology plays a vital role in improving energy harvesting and storage systems.



## Nano-Engineered Electrodes

Nanostructured electrodes offer:

- High surface area
- Faster charge transfer
- Improved energy storage capacity

These electrodes are used in batteries, supercapacitors, and fuel cells.

## Nanotechnology in Solar Cells

Nanomaterials enhance solar cell performance by:

- Improving light absorption
- Increasing conversion efficiency
- Reducing material and manufacturing costs

Applications include quantum dot solar cells and nanostructured photovoltaic devices.

## Chapter Completion Summary

This chapter highlighted recent inventions and applications of nanotechnology, including nanocomposites, nano-sensors, nanoencapsulation, water treatment technologies, and energy harvesting systems. These innovations demonstrate the transformative role of nanotechnology in healthcare, environment, materials science, and sustainable energy solutions.



# Mid Semester Test 1 – Sample Paper

Total Marks : 20

Time Allotted : 1 hour

## Instructions:

- The question paper consists of 2 sections: Section A and Section B.
- Section A has 5 questions of 2 marks each and Section B has 2 questions of 5 marks each.

## Section A ( $5 \times 2 = 10$ marks)

1. Explain the concept of wave-particle duality.
2. What is edge computing? Explain its importance in IoT, driverless cars, and health-care systems.
3. Discuss carbon nanomaterials and their role as nano additives. How do they enhance mechanical and electrical properties of materials?
4. An electron is confined within a region of width 1 nm. Estimate the minimum uncertainty in its velocity. (Given:  $m_e = 9.1 \times 10^{-31}$  kg)
5. Calculate the de Broglie wavelength of an electron accelerated through a potential difference of 150 V. (Given:  $h = 6.626 \times 10^{-34}$  J·s,  $m_e = 9.1 \times 10^{-31}$  kg,  $e = 1.6 \times 10^{-19}$  C)

## Section B ( $2 \times 5 = 10$ marks)

6. Compare the top-down and bottom-up approaches for nanomaterial synthesis. Explain the working principles of ball milling and sol-gel methods.
7. Explain the working principle of quantum computing. Discuss its potential applications in weather forecasting and cryptography.



# Answer Key

## Section A ( $5 \times 2 = 10$ marks)

1. Explain the concept of wave-particle duality.

**Answer:**

Wave-particle duality states that microscopic entities such as electrons and photons exhibit both wave-like and particle-like behavior. Light shows wave nature through interference and diffraction, and particle nature through the photoelectric effect. Similarly, electrons exhibit diffraction, confirming their wave nature.

2. What is edge computing? Explain its importance in IoT, driverless cars, and healthcare systems.

**Answer:**

Edge computing is a computing paradigm where data processing is performed close to the data source rather than in a centralized cloud.

**Importance:**

- **IoT:** Enables real-time processing of sensor data with reduced latency
- **Driverless cars:** Supports instant decision-making for safety-critical operations
- **Healthcare:** Allows real-time patient monitoring and faster diagnosis

3. Discuss carbon nanomaterials and their role as nano additives. How do they enhance mechanical and electrical properties of materials?

**Answer:**

Carbon nanomaterials such as graphene and carbon nanotubes possess exceptional mechanical strength and high electrical conductivity.

As nano additives, they:

- Increase tensile strength and durability
- Improve electrical and thermal conductivity
- Reduce material weight

They are widely used in composites, coatings, and electronic materials.



4. An electron is confined within a region of width 1 nm. Estimate the minimum uncertainty in its velocity.

**Answer:**

Using Heisenberg's Uncertainty Principle:

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

Given:

$$\Delta x = 1 \times 10^{-9} \text{ m}$$

$$\Delta p = \frac{h}{4\pi \Delta x}$$

$$\Delta p = \frac{6.626 \times 10^{-34}}{4\pi \times 1 \times 10^{-9}}$$

$$\Delta p \approx 5.27 \times 10^{-26} \text{ kg m/s}$$

Since  $\Delta p = m\Delta v$ :

$$\Delta v = \frac{\Delta p}{m}$$

$$\Delta v = \frac{5.27 \times 10^{-26}}{9.1 \times 10^{-31}}$$

$$\Delta v \approx 5.79 \times 10^4 \text{ m/s}$$

**Answer:** Minimum uncertainty in velocity is approximately  $5.8 \times 10^4 \text{ m/s}$ .

5. Calculate the de Broglie wavelength of an electron accelerated through a potential difference of 150 V.

**Answer:**

Kinetic energy gained by the electron:

$$E = eV = 1.6 \times 10^{-19} \times 150 = 2.4 \times 10^{-17} \text{ J}$$

Momentum:

$$p = \sqrt{2mE}$$



$$p = \sqrt{2 \times 9.1 \times 10^{-31} \times 2.4 \times 10^{-17}}$$

$$p \approx 6.61 \times 10^{-24} \text{ kg m/s}$$

de Broglie wavelength:

$$\lambda = \frac{h}{p}$$

$$\lambda = \frac{6.626 \times 10^{-34}}{6.61 \times 10^{-24}}$$

$$\lambda \approx 1.0 \times 10^{-10} \text{ m}$$

**Answer:** The de Broglie wavelength of the electron is approximately  $1.0 \times 10^{-10}$  m.

## Section B ( $2 \times 5 = 10$ marks)

6. Compare the top-down and bottom-up approaches for nanomaterial synthesis. Explain the working principles of ball milling and sol-gel methods.

**Answer:**

**Top-Down Approach:**

- Bulk materials are broken down into nanoscale structures
- Example: Ball milling

**Bottom-Up Approach:**

- Nanomaterials are built atom-by-atom or molecule-by-molecule
- Example: Sol-gel method

**Ball Milling:** A mechanical process where hardened balls collide with bulk material inside a rotating chamber, causing repeated fracturing and size reduction to nanoscale.

**Sol-Gel Method:** A chemical process where a liquid sol undergoes hydrolysis and condensation reactions to form a gel, which is then dried and calcined to produce nanomaterials.



7. Explain the working principle of quantum computing. Discuss its potential applications in weather forecasting and cryptography.

**Answer:**

Quantum computing uses principles of quantum mechanics such as superposition and entanglement. It operates using qubits, which can exist in multiple states simultaneously, enabling parallel computation.

**Applications:**

**Weather Forecasting:**

- Faster simulation of complex atmospheric models
- Improved prediction accuracy

**Cryptography:**

- Ability to break classical encryption algorithms
- Development of quantum-secure cryptographic methods

Thus, quantum computing has the potential to revolutionize data processing and security.

# Closing Note

I sincerely hope that these notes and the preparatory questions included alongside them prove helpful in strengthening your understanding and boosting your confidence for the examination you are preparing for.

As you revise, try not to rush through the content—pause at examples, work out the numericals on your own, and revisit sections that feel slightly uncomfortable. That discomfort usually signals learning in progress. Use these notes as a guide and a companion, not as something to be memorized line by line.

Wishing you the very best for your exams—may your preparation feel clear, structured, and calm when it matters most.

For future updates, refinements, and additional resources, keep checking **Noteify**:

<https://subhayu18.github.io/Noteify/>

If you have any doubts, suggestions, or simply wish to connect, feel free to reach out to me on LinkedIn:

<https://www.linkedin.com/in/subhayu-mukherjee-146421294/>

You can also use the direct contact options provided on the Noteify website itself.

**Regards,**  
Subhayu