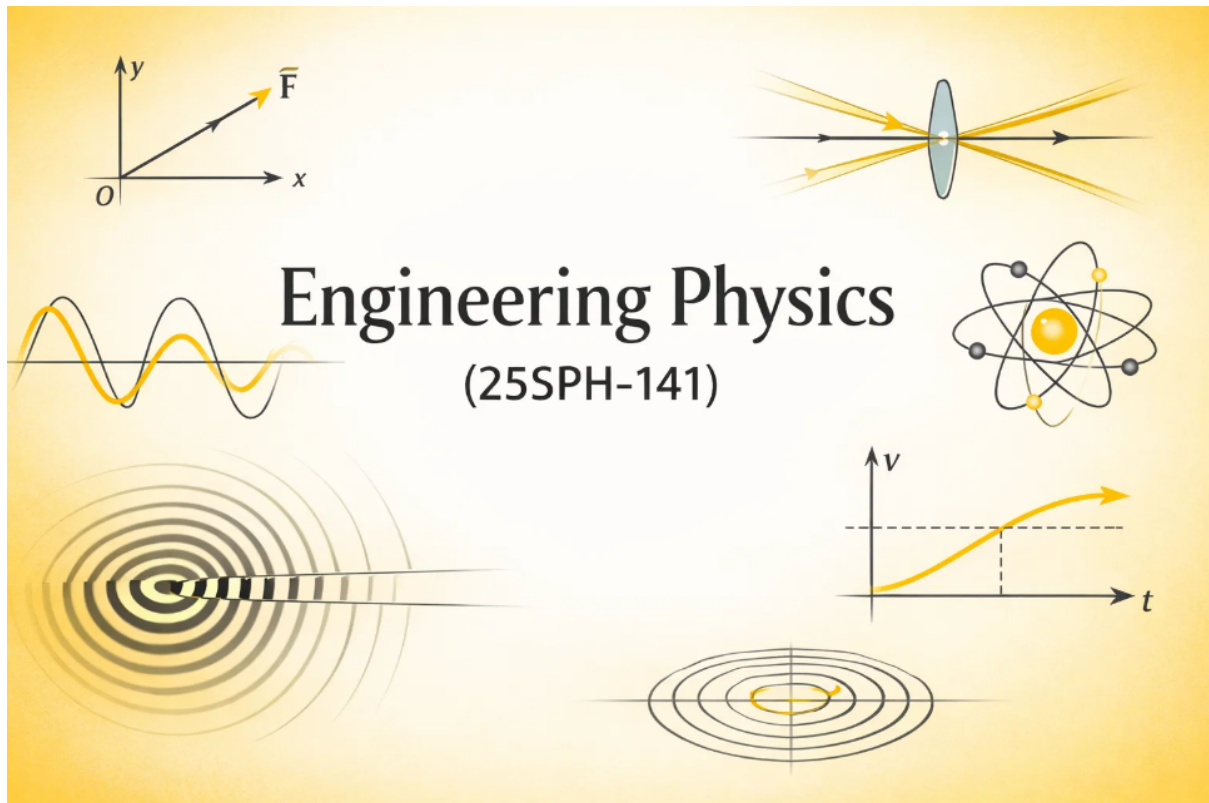




Unit 2 - Resources & Questions

Compiled by : Subhayu



Syllabus for Unit 2

Engineering Physics (25SPH-141)

Chapter 1 : Solid State Physics – Classification of solids, crystal structure, Bravais lattices, simple cubic (SC), body-centered cubic (BCC) and face-centered cubic (FCC) structures, atomic packing efficiency, coordination number and related parameters, Miller indices, interplanar spacing, superconductors, critical temperature, Meissner effect, Type-I and Type-II superconductors, applications of superconductivity

Chapter 2 : Recent Inventions in Solid State Physics – High-performance solid-state batteries with superionic electrolytes, graphene superconductivity – applications in biosensors and foldable smartphones, improved performance of electronic devices with minimum energy losses

Chapter 1

Solid State Physics

1.1 Introduction to Solids

1.1.1 What is a Solid?

A solid is a state of matter in which the constituent particles (atoms, ions, or molecules) are closely packed and arranged in a definite structure. Solids have fixed shape and volume due to strong intermolecular forces.

Core Idea

The properties of a solid depend largely on how its particles are arranged in space.

1.1.2 Types of Solids

Solids are broadly classified into two categories:

- Crystalline Solids
- Amorphous Solids

1.2 Classification of Solids

1.2.1 Crystalline Solids

These solids have a highly ordered and repeating arrangement of particles.

Characteristics:

- Long-range order
- Sharp melting point
- Anisotropic properties (properties vary with direction)

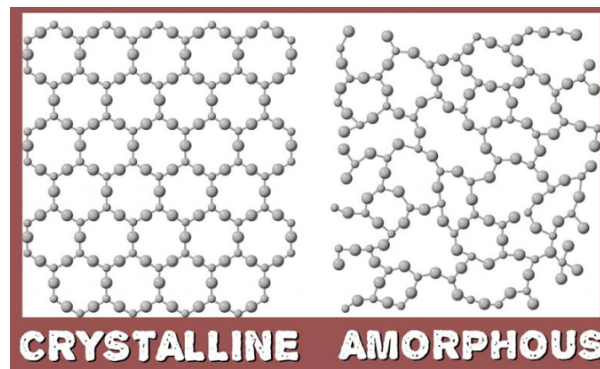


Figure 1.1: Crystalline vs Amorphous Solids structure

Examples: NaCl, Quartz, Diamond

1.2.2 Amorphous Solids

These solids lack long-range order.

Characteristics:

- Irregular arrangement
- No sharp melting point
- Isotropic properties (same in all directions)

Examples: Glass, Rubber, Plastics

Key Difference

Crystalline solids have a repeating pattern, whereas amorphous solids do not.

1.3 Crystal Structure

1.3.1 Definition

A crystal structure is the orderly, repeating arrangement of atoms, ions, or molecules in a three-dimensional space.

1.3.2 Lattice and Basis

- **Lattice:** A regular array of points in space
- **Basis:** A group of atoms associated with each lattice point



$$\text{Crystal Structure} = \text{Lattice} + \text{Basis}$$

Concept Insight

Think of a lattice as a framework and the basis as the atoms placed on that framework.

1.4 Bravais Lattices

1.4.1 Definition

Bravais lattices are the distinct lattice types that can fill space completely without leaving gaps.

There are **14 Bravais lattices** in three dimensions.

1.4.2 Types of Unit Cells

- Primitive (P)
- Body-centered (I)
- Face-centered (F)
- End-centered (C)

1.5 Cubic Crystal Systems

Cubic systems are the most important and simplest crystal structures.

1.5.1 Simple Cubic (SC) Structure

Description: Atoms are located at the corners of a cube.

Number of atoms per unit cell:

$$8 \times \frac{1}{8} = 1$$

Coordination Number: 6

Atomic Packing Efficiency (APE):

$$\approx 52.4\%$$

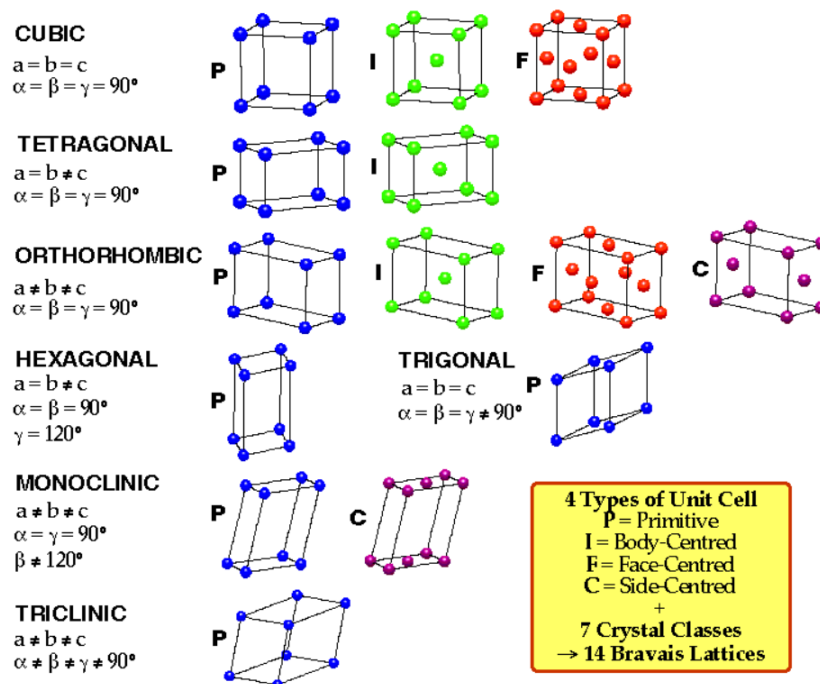


Figure 1.2: Bravais Lattices

1.5.2 Body-Centered Cubic (BCC) Structure

Description: Atoms at corners and one atom at the center.

Number of atoms per unit cell:

$$8 \times \frac{1}{8} + 1 = 2$$

Coordination Number: 8

Atomic Packing Efficiency:

$$\approx 68\%$$

1.5.3 Face-Centered Cubic (FCC) Structure

Description: Atoms at corners and centers of each face.

Number of atoms per unit cell:

$$8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$$

Coordination Number: 12

Atomic Packing Efficiency:

$$\approx 74\%$$



Comparison Insight

FCC has the highest packing efficiency, making it the most closely packed structure among SC, BCC, and FCC.

1.6 Atomic Packing Efficiency (APE)

1.6.1 Definition

Atomic Packing Efficiency is the fraction of volume in a crystal structure that is occupied by atoms.

$$\text{APE} = \frac{\text{Volume of atoms in unit cell}}{\text{Volume of unit cell}}$$

1.6.2 Solved Example

Find APE for SC structure.

Given: Atoms touch along edge, so:

$$a = 2r$$

Volume of atom:

$$\frac{4}{3}\pi r^3$$

Volume of unit cell:

$$a^3 = (2r)^3 = 8r^3$$

$$\text{APE} = \frac{\frac{4}{3}\pi r^3}{8r^3} = \frac{\pi}{6} \approx 0.524$$

Answer: 52.4%

1.7 Coordination Number

1.7.1 Definition

The coordination number is the number of nearest neighboring atoms surrounding a given atom.

- SC $\rightarrow$ 6
- BCC $\rightarrow$ 8



- FCC $\rightarrow$ 12

Quick Memory Tip

SC: 6, BCC: 8, FCC: 12 — increases with packing efficiency.

1.8 Relation Between Atomic Radius and Lattice Parameter

1.8.1 Simple Cubic

$$a = 2r$$

1.8.2 Body-Centered Cubic

Atoms touch along body diagonal:

$$\sqrt{3}a = 4r \Rightarrow a = \frac{4r}{\sqrt{3}}$$

1.8.3 Face-Centered Cubic

Atoms touch along face diagonal:

$$\sqrt{2}a = 4r \Rightarrow a = \frac{4r}{\sqrt{2}} = 2\sqrt{2}r$$

Important Formula

Remember where atoms touch:

- SC $\rightarrow$ edge
- BCC $\rightarrow$ body diagonal
- FCC $\rightarrow$ face diagonal

1.9 Summary

- Solids are classified as crystalline and amorphous
- Crystal structure = lattice + basis
- 14 Bravais lattices exist



- SC, BCC, FCC are key cubic structures
- Packing efficiency: $SC < BCC < FCC$
- Coordination number increases with packing density

Final Takeaway

Understanding crystal structures helps explain mechanical, electrical, and thermal properties of materials.

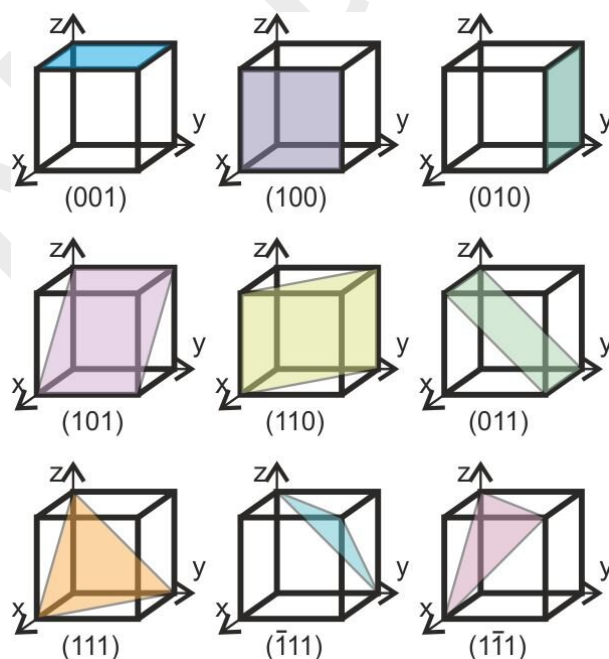
1.10 Miller Indices

1.10.1 Introduction

Miller indices are a set of three integers (hkl) used to denote the orientation of crystal planes in a lattice. They provide a compact and systematic way to represent planes in a crystal.

Core Idea

Miller indices describe the **orientation of planes**, not their position.



1. Determine the intercepts of the plane with the axes in terms of lattice constants a, b, c
2. Take reciprocals of the intercepts
3. Clear fractions to get smallest integers



4. Write as (hkl)

1.10.2 Example

A plane cuts axes at $2a, 3b, \infty$.

- Intercepts: $(2, 3, \infty)$
- Reciprocals: $(\frac{1}{2}, \frac{1}{3}, 0)$
- Multiply by 6: $(3, 2, 0)$

Miller indices: (320)

Important Note

If a plane is parallel to an axis, its intercept is ∞ , and its Miller index is 0.

1.11 Interplanar Spacing

1.11.1 Definition

Interplanar spacing d_{hkl} is the distance between two adjacent parallel planes with Miller indices (hkl) .

1.11.2 Formula for Cubic Crystals

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

where a is the lattice constant.

1.11.3 Solved Example

Find the interplanar spacing for $(1\ 1\ 1)$ plane in a cubic crystal.

$$d_{111} = \frac{a}{\sqrt{1^2 + 1^2 + 1^2}} = \frac{a}{\sqrt{3}}$$

Concept Insight

Higher the values of (hkl) , smaller is the interplanar spacing.



1.12 Superconductors

1.12.1 Definition

A superconductor is a material that exhibits zero electrical resistance and expulsion of magnetic field below a certain temperature.

1.12.2 Key Properties

- Zero electrical resistance
- Perfect diamagnetism

Key Feature

Superconductors allow current to flow indefinitely without energy loss.

1.13 Critical Temperature

1.13.1 Definition

Critical temperature (T_c) is the temperature below which a material becomes superconducting.

Example: Mercury becomes superconducting below 4.2 K.

Important Point

Above T_c , the material behaves like a normal conductor.

1.14 Meissner Effect

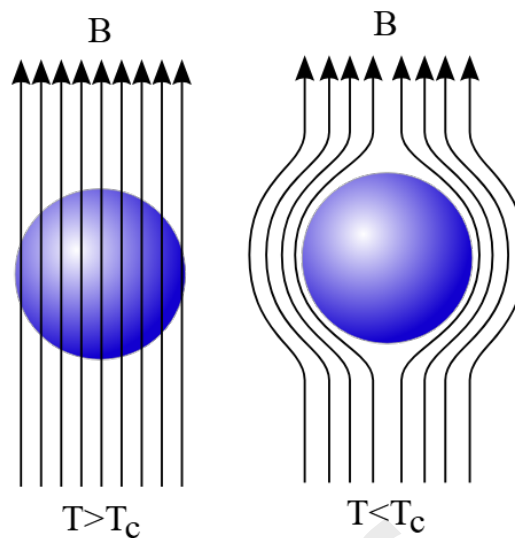
1.14.1 Definition

The Meissner effect is the complete expulsion of magnetic field lines from a superconductor when it is cooled below T_c .

1.14.2 Explanation

When a material becomes superconducting:

- Magnetic field inside becomes zero
- The material behaves as a perfect diamagnet



Concept Insight

Zero resistance alone does not define superconductivity — Meissner effect is essential.

1.15 Types of Superconductors

1.15.1 Type-I Superconductors

- Exhibit complete Meissner effect
- Have a single critical magnetic field
- Become normal abruptly

Examples: Lead, Mercury

1.15.2 Type-II Superconductors

- Exhibit partial Meissner effect
- Have two critical fields (H_{c1} and H_{c2})
- Allow magnetic flux in mixed state

Examples: Alloys, high-temperature superconductors

Comparison

Type-I: complete exclusion

Type-II: partial penetration of magnetic field



S.N	Type I (or) Soft superconductors	Type II (or) Hard superconductors
1.	It exhibits complete Meissner Effect.	It does not exhibit a complete Meissner Effect.
2.	They are completely diamagnetic.	They are not completely diamagnetic.
3.	Ex : Tin, Lead, Mercury, etc.,	Ex : Nb-Zr, Nb-Ti, Nb-Sn, V-Ga, etc.,
4.	$H_a \rightarrow$ Applied magnetic field $H_i \rightarrow$ Induced magnetic field	
5.	The value of H_c is always too low. It is about 0.1 tesla.	The values of H_c is high and it is about 30 tesla.
6.	They have only one critical magnetic field value.	They have two critical magnetic field values. Lower critical magnetic field [H_{c1}] and Higher critical magnetic field [H_{c2}].
7.	No mixed state exists.	Mixed state is present.
8.	These are called Soft superconductors.	These are called Hard superconductors.
9.	It requires low magnetic field to destroy the superconductivity.	It requires large magnetic field to destroy the superconductivity.
10.	It loses its magnetization abruptly.	It loses its magnetization gradually.

1.16 Applications of Superconductivity

1.16.1 Magnetic Levitation

Used in maglev trains for frictionless motion.

1.16.2 MRI Machines

Superconducting magnets provide strong and stable magnetic fields.

1.16.3 Power Transmission

Used for lossless transmission of electricity.

1.16.4 Particle Accelerators

Used to generate high magnetic fields.

Real-World Impact

Superconductivity has the potential to revolutionize energy, transport, and medical technology.



1.17 Summary

- Miller indices define crystal planes
- Interplanar spacing depends on (hkl)
- Superconductors show zero resistance and Meissner effect
- Type-I and Type-II differ in magnetic behavior
- Wide applications in technology

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Chapter 2

Recent Inventions in Solid State Physics

2.1 Introduction

2.1.1 Why Recent Advances Matter

Solid State Physics is at the heart of modern technological evolution. Recent inventions have significantly improved:

- Energy storage systems
- Electronic device efficiency
- Miniaturization and flexibility of devices

Big Picture

Modern innovations in solid state physics aim to make devices **faster, smaller, energy-efficient, and more sustainable.**

2.2 High-Performance Solid-State Batteries

2.2.1 Introduction

Solid-state batteries are next-generation batteries that use solid electrolytes instead of liquid or gel electrolytes.

2.2.2 Components of Solid-State Batteries

- Solid electrolyte



- Anode (often lithium metal)
- Cathode

2.2.3 Superionic Electrolytes

Definition: Superionic electrolytes are materials that exhibit very high ionic conductivity, comparable to liquids, while remaining in solid state.

Examples: Lithium phosphorus oxynitride (LiPON), sulfide-based electrolytes

Core Concept

Superionic conductors allow ions to move freely in a solid lattice, enabling efficient charge transport.

2.2.4 Advantages of Solid-State Batteries

- Higher energy density
- Improved safety (no leakage or explosion risk)
- Longer lifespan

2.2.5 Applications

- Electric vehicles (EVs)
- Portable electronics
- Renewable energy storage

2.2.6 Solved Insight Question

Why are solid-state batteries safer than conventional batteries?

Answer: Because they use solid electrolytes, eliminating risks of leakage, thermal runaway, and flammability associated with liquid electrolytes.

2.3 Graphene Superconductivity

2.3.1 Introduction to Graphene

Graphene is a single layer of carbon atoms arranged in a hexagonal lattice.

Key Properties:



- Extremely high electrical conductivity
- High mechanical strength
- Flexibility and transparency

2.3.2 Superconductivity in Graphene

Under certain conditions (e.g., twisted bilayer graphene), graphene exhibits superconductivity.

Breakthrough Insight

Twisting two graphene layers at a “magic angle” enables superconductivity — a major discovery in condensed matter physics.

2.3.3 Applications in Biosensors

- High sensitivity detection of biomolecules
- Used in glucose sensors, DNA detection

2.3.4 Applications in Foldable Smartphones

- Flexible and bendable displays
- Transparent conductive layers
- Lightweight materials

2.3.5 Solved Example

Why is graphene suitable for foldable devices?

Answer: Because of its exceptional flexibility, strength, and electrical conductivity, allowing it to maintain performance even under bending.

2.4 Improved Performance of Electronic Devices

2.4.1 Need for Improvement

Modern devices demand:

- High speed
- Low power consumption



- Minimal energy loss

2.4.2 Techniques Used

- Use of advanced semiconductor materials
- Miniaturization (nanotechnology)
- Efficient heat dissipation systems

2.4.3 Reducing Energy Losses

- Superconducting materials eliminate resistive losses
- Low-resistance interconnects improve efficiency
- Better insulation and materials design

Key Concept

Energy loss in electronic devices mainly occurs due to resistance — reducing resistance improves efficiency.

2.4.4 Real-World Examples

- Energy-efficient processors (used in smartphones and laptops)
- LED technology replacing traditional bulbs
- High-speed computing devices

2.5 Future Scope

2.5.1 Emerging Trends

- Quantum computing materials
- Room-temperature superconductors
- Advanced nanomaterials

Future Insight

The future of solid state physics lies in combining material science with quantum technology.



2.6 Summary

- Solid-state batteries offer safer and efficient energy storage
- Graphene enables flexible electronics and advanced sensing
- Modern devices focus on minimizing energy losses
- Continuous innovations are shaping next-generation technology

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Mid Semester Test 2 – 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 crystal structure. How is it related to lattice and basis?
2. Explain how modern electronic devices achieve improved performance with minimum energy losses. Illustrate with suitable examples.
3. Differentiate between crystalline and amorphous solids with suitable examples and properties.
4. Determine the Miller indices of a plane that cuts the axes at $2a$, $3b$, and c .
5. Discuss the concept of graphene superconductivity and explain its applications in biosensors and foldable smartphones.

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

6. Derive the expression for interplanar spacing in a cubic crystal and calculate d_{110} .
7. Explain the working principle and advantages of high-performance solid-state batteries with superionic electrolytes.

Answer Key with Explanations

Section A

1. Crystal Structure, Lattice and Basis

A crystal structure is the orderly and periodic arrangement of atoms, ions, or molecules in three-dimensional space.

Relation:

$$\text{Crystal Structure} = \text{Lattice} + \text{Basis}$$

- **Lattice:** A regular array of points in space representing positions of repeating units.
- **Basis:** A set of atoms associated with each lattice point.

Explanation: Each lattice point acts as a placeholder. When a basis is attached to every lattice point, the entire crystal structure is generated. Thus, the lattice gives the geometry, while the basis gives the physical identity.

Conceptual Insight

Lattice is purely mathematical, whereas basis is physical — together they form the real crystal.

2. Improved Performance of Electronic Devices

Modern electronic devices achieve high performance with minimal energy losses using advanced solid-state principles:

- **Low-resistance materials:** Reduces Joule heating losses
- **Miniaturization:** Shorter pathways reduce energy dissipation
- **Efficient semiconductors:** Better control of charge carriers
- **Heat management:** Prevents energy waste as heat

Examples:



- **LED bulbs:** Convert more electrical energy into light rather than heat
- **Modern processors:** Use low-power transistors for efficiency
- **Superconductors:** Eliminate resistance completely in specialized systems

Key Idea

Energy loss $\propto$ resistance — minimizing resistance is the primary goal in device optimization.

3. Crystalline vs Amorphous Solids

Property	Crystalline Solids	Amorphous Solids
Structure	Long-range ordered	No long-range order
Arrangement	Periodic	Random
Melting Point	Sharp	Range (no definite point)
Physical Nature	Anisotropic	Isotropic
Cleavage	Breaks along planes	Irregular fracture
Examples	NaCl, Diamond	Glass, Rubber

Exam Insight

Always mention anisotropic vs isotropic — it is a key differentiating point.

4. Miller Indices Calculation

Given intercepts: $(2a, 3b, c)$

- Convert to unit form: $(2, 3, 1)$
- Take reciprocals: $(\frac{1}{2}, \frac{1}{3}, 1)$
- Multiply by LCM (6): $(3, 2, 6)$

Final Answer: (326)

Explanation: Miller indices represent the orientation of the plane, not its position. Larger intercept $\rightarrow$ smaller index and vice versa.

Tip

Parallel to an axis $\Rightarrow$ intercept $\infty \Rightarrow$ index 0.

5. Graphene Superconductivity and Applications

Graphene is a two-dimensional material with exceptional electrical and mechanical properties. Under special conditions (like twisted bilayer graphene), it exhibits superconductivity.

**Why Graphene is Special:**

- High electrical conductivity
- Mechanical strength
- Flexibility and transparency

Applications:**(a) Biosensors**

- Detect biomolecules with high sensitivity
- Used in medical diagnostics (e.g., glucose sensors)

(b) Foldable Smartphones

- Flexible displays
- Transparent conductive electrodes
- Durable and lightweight components

Concept Insight

Graphene bridges electronics and flexibility — enabling next-gen wearable and foldable tech.

Section B**6. Interplanar Spacing in Cubic Crystal**

For a cubic lattice, interplanar spacing is:

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

Explanation: This formula arises from geometric analysis of planes intersecting the cubic lattice. The spacing depends on how densely planes are arranged, which is determined by (hkl) .

Calculation for (110):

$$d_{110} = \frac{a}{\sqrt{1^2 + 1^2 + 0^2}} = \frac{a}{\sqrt{2}}$$

Final Answer:

$$d_{110} = \frac{a}{\sqrt{2}}$$

**Key Insight**

As (hkl) increases, planes become closer $\rightarrow$ spacing decreases.

7. Solid-State Batteries with Superionic Electrolytes

Working Principle: Solid-state batteries replace liquid electrolytes with solid ones. During operation:

- Ions move through the solid electrolyte
- Electrons flow through external circuit

Role of Superionic Electrolytes:

- Provide very high ionic conductivity
- Enable fast ion transport in solid medium

Advantages:

Feature	Benefit
Solid electrolyte	No leakage
High conductivity	Faster charging
Thermal stability	Safer operation
Compact design	Higher energy density

Explanation: Unlike conventional batteries, the absence of liquid electrolytes eliminates risks like leakage and explosion, while improving efficiency.

Final Insight

Solid-state batteries are a major step toward safer and longer-lasting energy storage systems.

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