



Crystallography & Mineralogy

A book by Career Avenues

As per IIT-JAM Syllabus
GEOLOGY / EARTH SCIENCE



Crystallography And Mineralogy

Introduction

Mineralogy is the study of minerals. It is a subject of geology that deals with the crystal structure and chemical, physical and optical properties of minerals. It also includes the description of properties of minerals, that branch is called descriptive mineralogy.

Crystallography is a subset of mineralogy that need special attention. The minerals are made up of atoms and molecules in an orderly fashion. This ordered manner will reflect in the appearance and other properties of minerals. Crystallography mainly deals with the symmetry, classification and forms of crystals. The symmetry elements can be represented by stereographic projections.

The remaining portions of mineralogy are divided as crystal chemistry and physical and optical properties, structure and description of silicates and non-silicates. Silicate minerals are the important rock-forming minerals. While non-silicate forms economically important deposits.

X-ray diffraction (XRD) is used for the identification of mineral phases by determining the crystal structure.

Chapter 1
Crystallography– symmetry and crystal systems

JAM year	Weightage (Marks)
2020	<div>SAMPLE</div>
20177	
2016	
2015	
Average	

Chapter 1

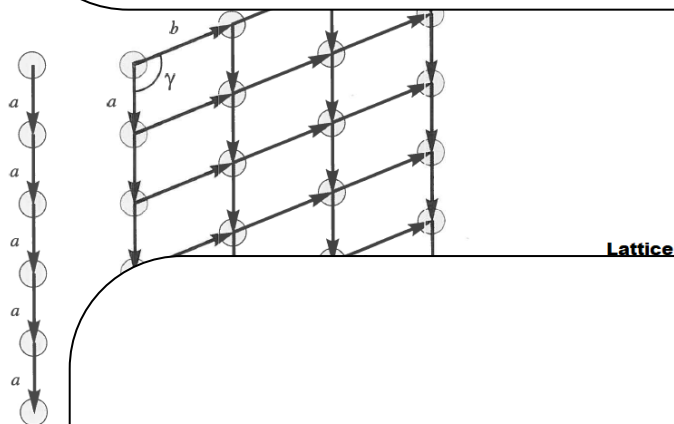
Crystallography– symmetry and crystal systems

1.1. Crystallography - Introduction

- Crystals have unique properties of crystals.
- Minimum symmetry. This structure of crystals.
- Symmetry.
 - The
 - The
- A lattice form a crystal.

1.2.

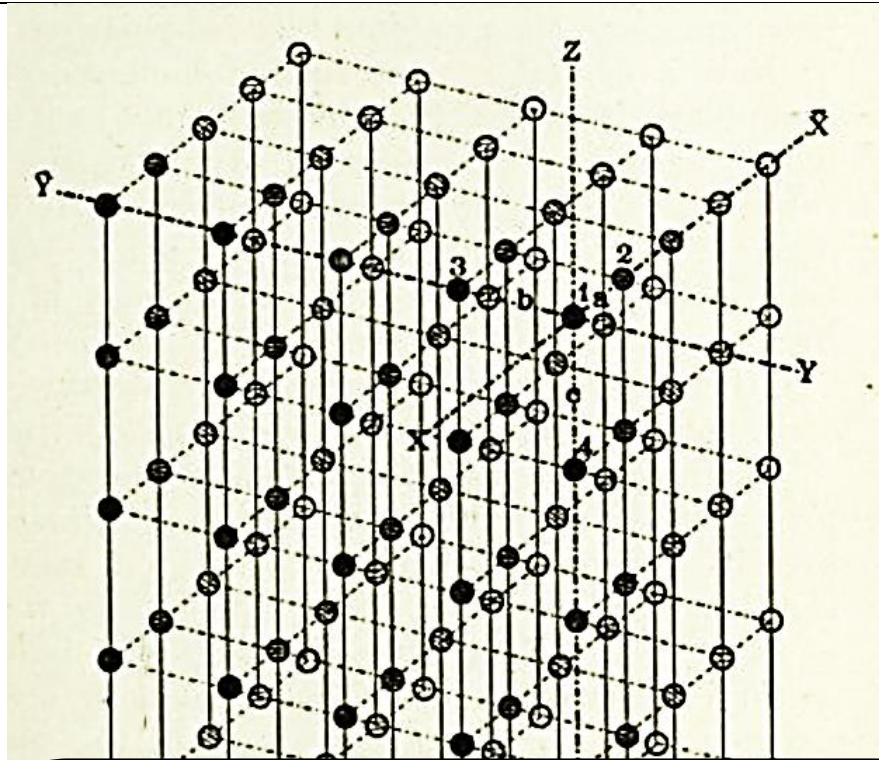
- Planar
- Repetitive
- The



- The five dimensional plane lattice unit measures.
- Diamond

1.3. Space

- A regular lattice at the inter
- If the two allow for



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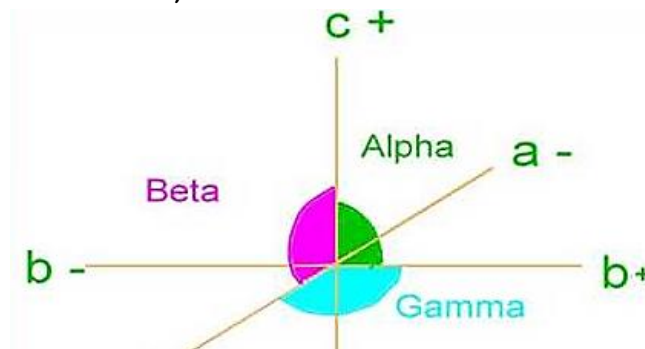
1.4. Un

- The uni
structur
- The vol
- The edge
at a point ca

- The crystal axes have positive and negative ends

axes	a	B	c
Positive/negative			
Positive	To the front	To the right	Upward
Negative	To the back	To the left	downward

- The angle between b and c $\rightarrow \alpha$
The angle between a and c $\rightarrow \beta$
The angle between a and b $\rightarrow \gamma$



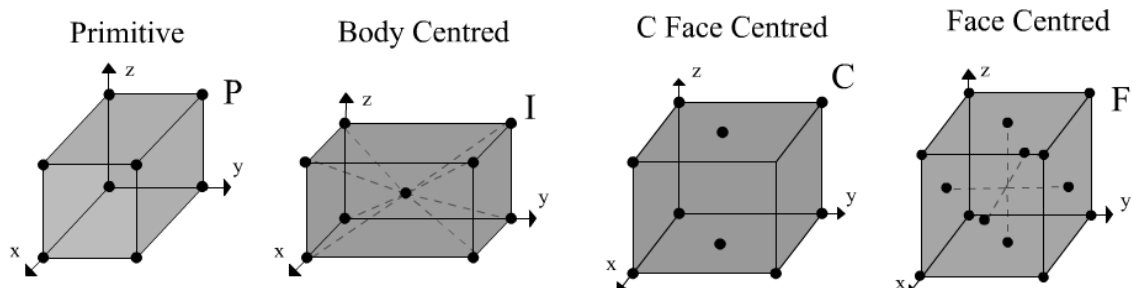
1.5.

- Bravais lattices describe the arrangement of lattice points in space
- The 14 Bravais lattices are classified into six groups based on the shape of the unit cell. These are called crystal systems.
- Not all lattices are primitive
- Non-primitive lattices have additional lattice points inside the unit cell
- Body-centred (I)
- Face-centred (F)
- Primitive (P)
- Body-centred (I)

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used to
space
every
lattice

Face centred (C) unit cells contain lattice nodes on the corners and two opposite sides
Face centred (F) unit cells contain lattice nodes at the corners and the centre of each face.



- Crystal systems
 - The primary method of classification of crystals.
 - 14 Bravais lattices are grouped into six groups based on the shape of the unit cell. These are called crystal systems.

- Six crystal systems are

- Isometric system
- Tetragonal system
- Hexagonal system
- Orthorhombic system
- Monoclinic system
- Triclinic system
- 14 Types of Bravais lattices

- Out of these six crystal systems, the first three are called the **isometric crystal systems** because the dimensions of the unit cell are equal and the angles between the edges are also equal.

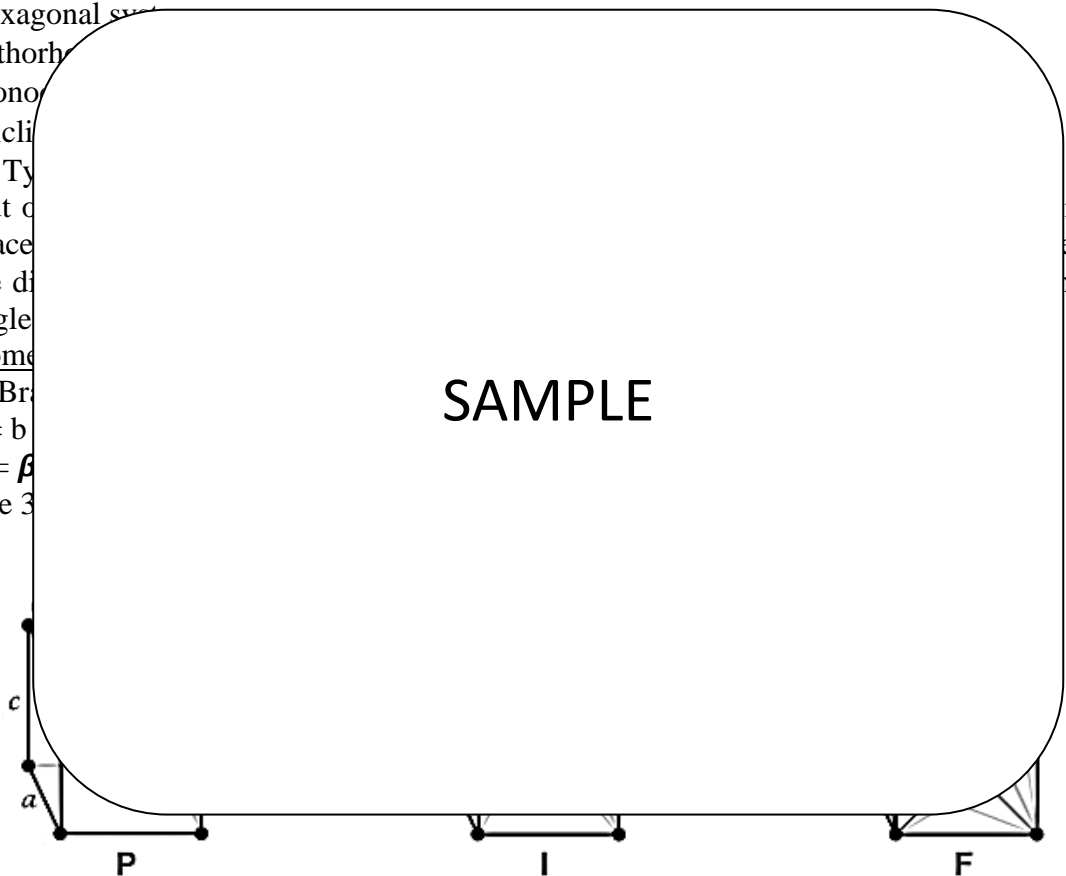
Isometric Crystal Systems

- In Bravais lattices, the following relations are observed:

$$a = b = c$$

$$\alpha = \beta = \gamma = 90^\circ$$

- The three types of isometric crystal systems are



- These three possible cubic Bravais lattices are,

- Primitive (or Simple) Cubic Cell (P)
- Body-Centred Cubic Cell (I)
- Face-Centred Cubic Cell (F)

- Examples: Polonium has a simple cubic structure, Iron has a body-centred cubic structure, and copper has a face-centred cubic structure.

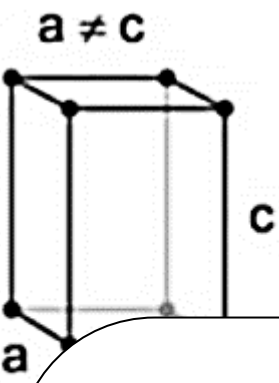
Tetragonal Systems

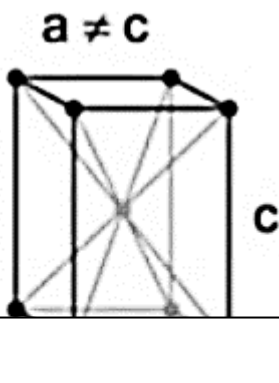
- In tetragonal Bravais lattices, the following relations are observed:

$$a = b \neq c$$

$$\alpha = \beta = \gamma = 90^\circ$$

- The two types of tetragonal systems are simple tetragonal cells and body-centred tetragonal cells,





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Simple
Centered
Centered
Centered

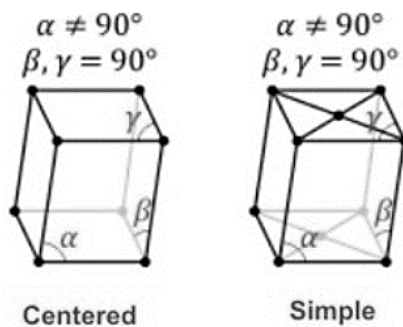
- Stru
- Orti
- The
- $a \neq$
- $\alpha =$
- The



Simple

Monoclinic Systems

- Bravais lattices having monoclinic systems obey the following relations:
 $a \neq b \neq c$
 $\beta = \gamma = 90^\circ$ and $\alpha \neq 90^\circ$
- The two possible types of monoclinic systems are primitive and base centred monoclinic cells,



Triclinic System

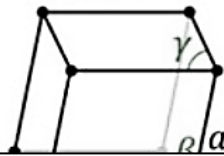
- There exists only one type of triclinic Bravais lattice, which is a primitive cell. It obeys the following relationships:
 $a \neq b \neq c$
 $\alpha \neq \beta \neq \gamma$
- An illustration of the primitive triclinic cell is

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Hexagonal System

- Only two types of hexagonal Bravais lattices exist: primitive and body-centered. They obey the following relationships:
 $a = b \neq c$
 $\alpha = \beta = \gamma = 120^\circ$
- An illustration of the primitive rhombohedral cell is

$\alpha, \beta, \gamma \neq 90^\circ$





- Hexagonal primitive cell
- The origin of the hexagonal system is at the center of the hexagon, giving rise to the following relationships:
 $a = b \neq c$
 $\alpha = \beta = 120^\circ, \gamma = 90^\circ$
- An illustration of the primitive hexagonal cell is

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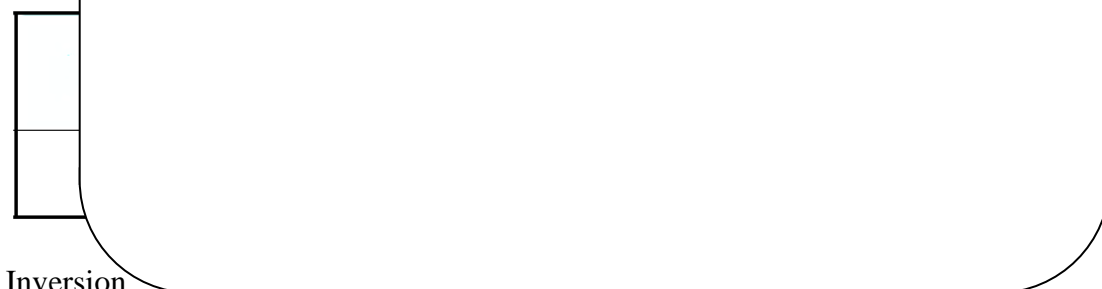
- Thus, it can be noted that all 14 possible Bravais lattices differ in their cell length and angle relationships. It is important to keep in mind that the Bravais lattice is not always the same as the crystal lattice.

1.6. Point symmetry

- Point symmetry
- Motif of a crystal structure
- Point
- Reflection
- Rotation
- Inversion
- Rotation
- Rotation
- Not
- A₁ of
- Rotation
- Symmetry

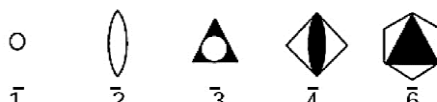
R		
1-fold	360° rotation	none
2-fold	180° rotation	
3-fold	120° rotation	

- Reflection
- A reflection pattern
- Reflection
- Monoclinic has
- none.



- Inversion
 - If a crystal has inversion or centre of symmetry, any line drawn through the origin will find identical features equidistant from the origin on opposite sides of the crystal.
 - Inversion symmetry is indicated by the letter 'i'.
- Compound symmetry operations

- Rotoinversion
- Rotoinversion axis is defined as an axis through the centre of the crystal, such that a rotation about the axis followed by inversion through the centre of the crystal results in the crystal appearing identical to the original.
- There are three types of roto-inversion axes, $\bar{A}_1, \bar{A}_2, \bar{A}_3$
- 1-fold roto-inversion axis (\bar{A}_1) is the same as a mirror plane. So, $\bar{A}_1 = A_1 + m$
- 2-fold roto-inversion axis (\bar{A}_2) is the same as a 2-fold rotation axis through the centre of the crystal. So, $\bar{A}_2 = A_2 + m$
- 3-fold roto-inversion axis (\bar{A}_3) is the same as a 3-fold rotation axis through the centre of the crystal. So, $\bar{A}_3 = A_3 + m$
- 4-fold roto-inversion axis (\bar{A}_4) is the same as a 4-fold rotation axis through the centre of the crystal. So, $\bar{A}_4 = A_4 + m$
- 6-fold roto-inversion axis (\bar{A}_6) involves 60° rotation followed by inversion through the centre. \bar{A}_6 is same as a 3-fold rotation axis at right angle to a mirror. $\bar{A}_6 = A_3 + m$



1.7. Symmetry

- Symmetry
- Centre of symmetry
- Mirror plane
- Axis of symmetry
- Axes of symmetry

1.8. Point Group

- There are 32 point groups in the crystal system.
- Each point group is defined by its symmetry elements.
- Each point group is represented by a symbol (Hermann-Mauguin symbol).
- Name of point group (crystal class) and their Hermann-Mauguin symbol

Crystal system	Crystal class/ point	Name of the class
Triclinic	<div>SAMPLE</div>	
Monoclinic		
Orthorhombic		
Tetragonal		
	4/m	Tetragonal-dipyramidal
	422	Tetragonal-trapezohedral
	4mm	Ditetragonal-pyramidal
	42m	Tetragonal-scalenohedron
<div>SAMPLE</div>		
	6mm	Dihexagonal-pyramidal
	$\bar{6} m2$	Ditrigonal-dipyramidal
	6/m2/m2/m	Dihexagonal-dipyramidal
Isometric	23	Tetrahedral

	$2/m\bar{3}$	Diploidal
	432	Gyroidal

- Symmetry
- System

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cubic

tetragonal

	$4mm$	1		4	
	$\bar{4}2m$		2 (3)	1	2
	$4/m$	1		1	i
	$\bar{4}$		(1)	1	
	4	1			
hexagonal	$6/m2/m2/m$	1	6	7	i
(hexagonal)	622	1	6		
	$6mm$	1		6	
	$\bar{6}2m$		(1) 2 1	3 (4)	

hexagonal
(trigonal)

orthorhombic

monoclinic

triclinic

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- Hermann-Mauguin notation is used to represent the symmetry elements in point groups.
- m - mirror planes
- 1, 2, 3, 4, 6 - rotational axes (1-fold, 2-fold, 3-fold....etc.)

1, 2, 3, 4, 6 - rotoinversion axes (1-fold, 2-fold, etc.)

i – Inversion

- Determination of Hermann-Mauguin notation: example
- Hermann-Mauguin notation of an orthorhombic crystal

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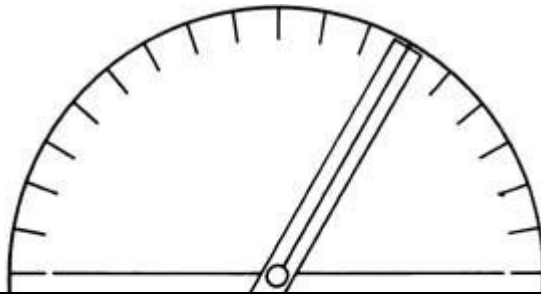
- There is a 2-fold axis of symmetry.
- Step I: The crystal has a 2-fold axis of symmetry.
- Step II: The crystal has a 2-fold axis of symmetry.
- Step III: The crystal has a 2-fold axis of symmetry.

$2 / m 2 / m 2 / m$

- Steno's law of crystal angles
- This law states that the angles of crystals are constant regardless of their sizes and shapes.

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- Measurement of crystal angles
- Crystal angles can be measured with an instrument called a goniometer.
- Simple contact goniometer



1.9. Space

- The space group is a combination of symmetry operations.
- Combination of glide planes and space groups.
- A glide plane is a combination of a reflection and a translation.
- A screw axis is a combination of a rotation and a translation.
- Glide planes and screw axes are part of the point group symmetry.
- A screw is produced by a combination of translation a specific distance and direction followed by a rotation. The axis about which rotation occurs is called the screw axis.

1.10. Crystal faces

- A plane that is parallel to the faces of a crystal.
- Crystal faces are the result of the growth of a crystal from a solution or melt.
- Law of crystal faces states that the faces of a crystal are parallel to the faces of the parent crystal.
- Law of rational indices states that the intercepts of the faces of a crystal on the axes are in the ratio of small integers.

1.11. Axial

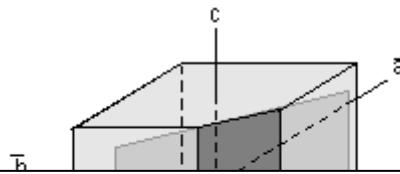
- Axial ratio is the ratio of the lengths of the axes of a crystal.
- Axial ratio is determined by the ratio of the lengths of the axes of a crystal.
- Or, Axial ratio is the ratio of the lengths of the axes of a crystal.
- For example, the axial ratio of a crystal is 1:1:1.

For
a

1.12.

- We
 - We
 - the
 - Exa
 - A c
- As an c axis.

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for thi

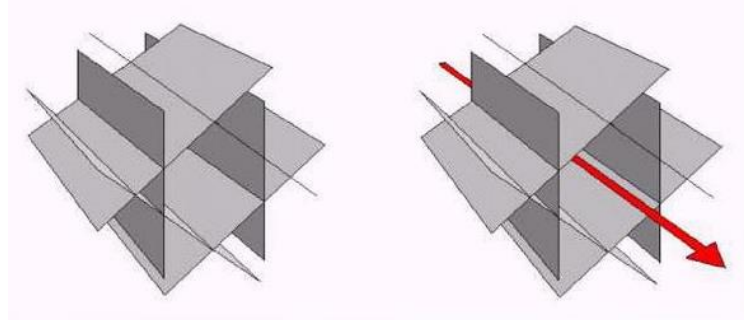
- Miller
- Miller
- planes
- The or
- (or any
- • (h,k,
- Nega
- [hkl]
- <hkl>
- (hkl) represents a plane
- {hkl} represents a family of planes
- Determination of Miller index of a plane
 - Step I: Determine the intercepts (a,b,c) of the plane along the crystallographic axes, in terms of unit cell dimensions.
 - Step II: Take the reciprocals of the intercepts.
 - Step III: Clear fractions and reduce to lowest terms by multiplying each intercept by the denominator of the smallest fraction.

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- Step IV: If a plane has negative intercept the negative number is denoted by a bar ($\bar{}$) above the number.
- Step V: The three indices are written in square brackets.
- Miller indices
- For the three axes in the Cartesian coordinate system. Consider a plane in the first octant. The intercepts on the three axes are a , b and c . The Miller indices are $h = \frac{1}{a}$, $k = \frac{1}{b}$ and $l = \frac{1}{c}$.

1.13. 2

- A zone axis is a line of intersection of two or more crystallographic planes. It is denoted by $[uvw]$.



- The zone axis is denoted by $[uvw]$.

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Practice questions

1. The total number of Bravais lattices.

- a. 6
- b. 14
- c. 15
- d. 23

2.

SAMPLE

- a.
- b.
- c.
- d.

3. Which of the following is not a valid Miller index for a crystal plane?

- a. (100)
- b. {100}
- c. $\{100\}$
- d. $\{100\}$

4.

- a.
- b.
- c.
- d.

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5.

- a.
- b.
- c.
- d.

6.

- a. $\frac{2}{\sqrt{2}}$
- b. $\frac{2}{\sqrt{3}}$
- c. $\frac{3}{\sqrt{2}}$
- d. $\frac{3}{\sqrt{3}}$

7. Choose the correct answer to the question.

1. The probability of a person being a doctor is 0.001. The probability of a person being a lawyer is 0.002. The probability of a person being a judge is 0.003. The probability of a person being a politician is 0.004. The probability of a person being a scientist is 0.005. The probability of a person being a teacher is 0.006. The probability of a person being a nurse is 0.007. The probability of a person being a police officer is 0.008. The probability of a person being a firefighter is 0.009. The probability of a person being a soldier is 0.010.

a. 0.001

b. 0.002

c. 0.003

d. 0.004

8. Find the probability of a person being a doctor, a lawyer, a judge, a politician, a scientist, a teacher, a nurse, a police officer, a firefighter, or a soldier.

a. 0.001

b. 0.002

c. 0.003

d. 0.004

9. Match the following classes in Group I to symbols in Group II

Group I	Group II
P	
C	
I	
S	

a. P

b. P

c. P

d. P

10. Hermann-Mauguin symbol of the following crystal

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- a. $4/m\bar{3}2$
- b. $4/m\bar{2}$
- c. $4/m4/m4/m$
- d. $4/m2m2/m$

11. A crystal face has the following intercepts for the crystallographic axes a, 1a2, 1c The Miller index of the face is

Multiple Choice

12. F

- a. F
- b. F
- c. F
- d. F

SAMPLE

13. V

- a. 2
- b. 3
- c. 4
- d. 6

14. V

S

- a. 2-fold axis
- b. 3-fold axis
- c. 4-fold rotoinversion axis
- d. 6-fold rotoinversion axis

impler

15. Which of the following symbol(s) does NOT represents a point group(s) in the hexagonal system?

- a. $\bar{3}2/m$
- b. $2/m\bar{3}$

- c.
- d.

16.

- a.
- b.
- c.
- d.

SAMPLE

17.

- a.
- b.
- c.
- d.

18. Which

- a. Tetragonal-dipyramidal
- b. Gyroidal
- c. Dihexagonal-dipyramidal
- d. Dipyramidal

19. How

- a. 2
- b. 6
- c. 3
- d. 4

SAMPLE

Answers

1. b
- 2.
- 3.
- 4.
- 5.
- 6.
- 7.
- 8.
- 9.
- 10
- 11
- 12
- 13
- 14
- 15
- 16
- 17.
18. b,
19. a, c, d

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2020	<p>If (326) is the Miller Index of a crystal face, then the value of x in the corresponding Miller Index $(x\bar{2}6)$ is _____.</p> <p>Mark: 1</p> <p>Ans 3</p> <p>Explanation: $(\bar{4}1h0) \rightarrow (hkl)$</p> <p>We know, $h+k+i=0$</p> <p>1).</p>
2017	<p>43. The Weiss symbol of a crystal face is $4a : 2b : c$. The value of h in the corresponding Miller Index (hkl) is _____.</p> <p>Mark: 1</p>

