BYJU'S Classes

Solid State

Magnetism in Solids and Curie Temperature

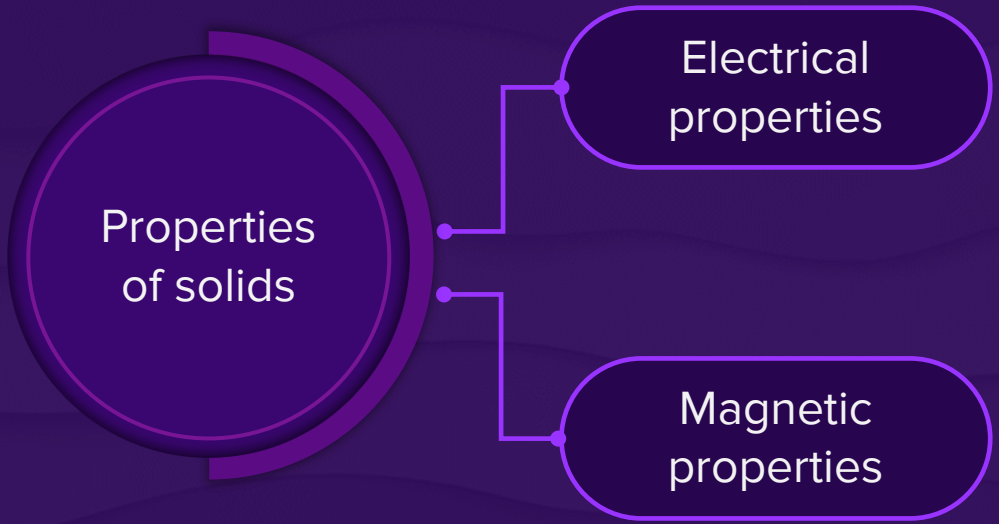
What you already know

- Types of stoichiometric defect
- Effect of Schottky and Frenkel defect on properties of crystal
- Types of non-stoichiometric
- Electrical properties of solids
- Aspects of band theory
- Conduction of electricity in metals
- Insulators and semiconductors

What you will learn

- Properties of solids
- Magnetic properties
- Classification of substances
- Paramagnetic substances
- Diamagnetic substances
- Ferromagnetic substances
- Antiferromagnetic substances
- Ferrimagnetic substances
- Curie point
- Practice questions

Properties of Solids



Which of the following defects in the crystal may lower the density?

BOARDS MAIN

(a) Interstitial defect

(b) Vacancy defect

(c) Schottky defect

(d) Impurity defect

Solution

(a) Interstitial defect:
Arises when some small foreign atoms (like B, C, N, H) are trapped in interstitial voids of the lattice without any chemical reaction. Density of crystal increases.

(b) Vacancy defect:

Such defect arises when some of the lattice sites in the crystal are vacant. Density of crystal decreases.

(c) Schottky defect:

It consists of ion vacancy in a crystal lattice, but the stoichiometry of a compound (and thus, electrical neutrality) is retained.

Schottky defect decreases the density of the substance.

(d) Impurity defect:

Sometimes have a decrease in density and sometimes increase in density.

Hence, options (b), (c) and (d) are the correct answers.

A non-stoichiometric compound Fe_7S_8 consists of iron in both Fe^{2+} and Fe^{3+} forms and sulphur is present as sulphide ions. If the percentage of cation vacancies relative to Fe^{2+} ions present initially (as ideal crystal of FeS) is 'x', then the value of 10x is:

BOARDS MAIN

Solution

- Initially ideal crystal present is FeS or $Fe^{2+}S^{2-}$.
- Cationic vacancies means some of the Fe^{2+} leaves their place.
- To balance the total charge the remaining some ferrous ions (Fe^{2+}) is converted into ferric ions (Fe^{3+}).
- Let's assume we have 3 $Fe^{2+} \longrightarrow$ 2 Fe^{3+}, after converting to ferric ions the charge remains same i.e. +6 and 1 Fe is missed i.e. vacancy defect occurs.
- Now, in Fe_7S_8 we have 8 S^{2-} means charge is = 8 × (−2) = −16.

- Let cations of Fe^{3+} is x, so charge will be +3x
- So, remaining cations of Fe^{2+} will have charge equal to 2(7 − x)
- And (+3x) + 2(7 − x) = + 16. So, total charge will be −16 + 16 = 0

$$(+3x) + 2(7 - x) = +16$$
$$14 + x = 16$$
$$x = 2$$

- So, out of 7 ions there are 2 Fe^{3+} ions i.e. 1 vacancy defect.
- We can say FeS is nothing but Fe_8S_8 and the non-stoichiometric compound is Fe_7S_8 having 1 vacancy defect as calculated.
- Percentage of vacancy defects (x) = (1 / 8) × 100 = 12.5%.
- **Therefore, the value of 10x is 125.**

Magnetic Properties

Every substance has some **magnetic properties** associated with it. The origin of these properties lies in the **electrons**.

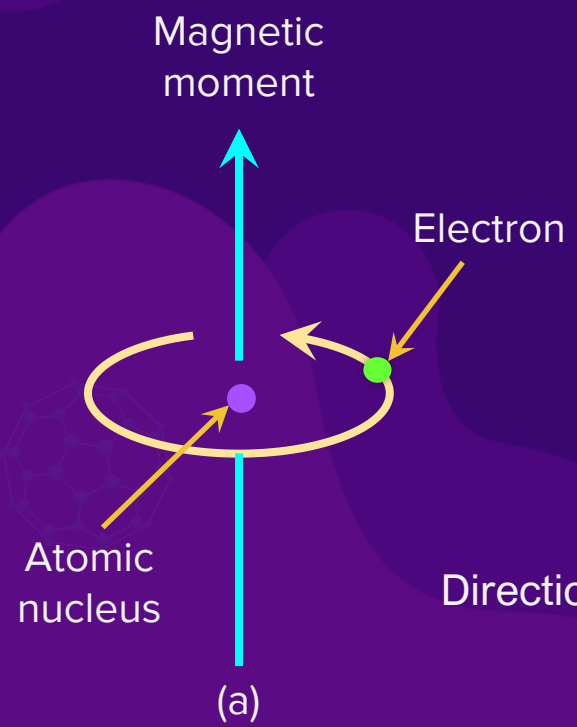
Each electron in an atom behaves like a tiny magnet.

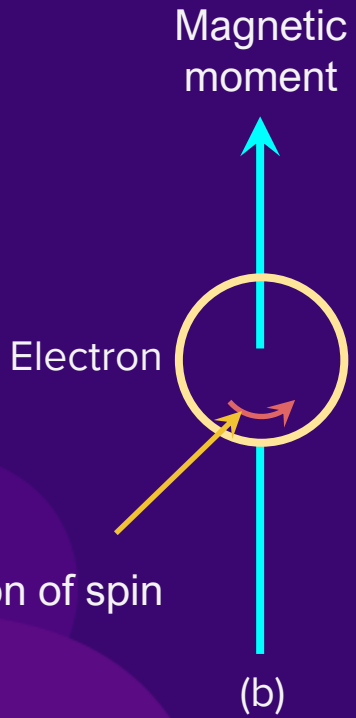
Magnetic moment of an electron originates from **two types of motion**.

(1) Its **orbital** motion around the nucleus.

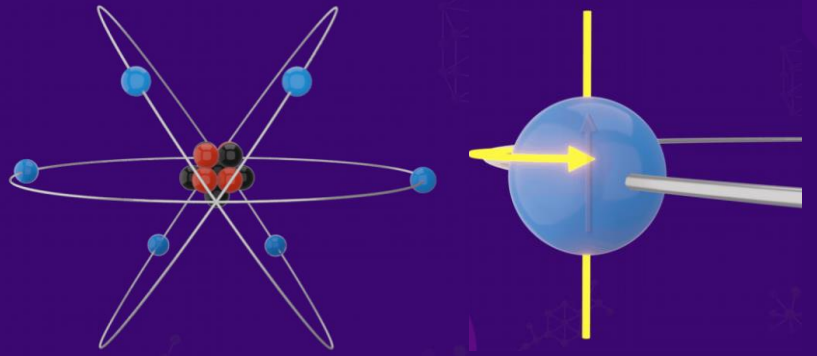
(2) Its **spin** around its own axis.

Magnetic Properties



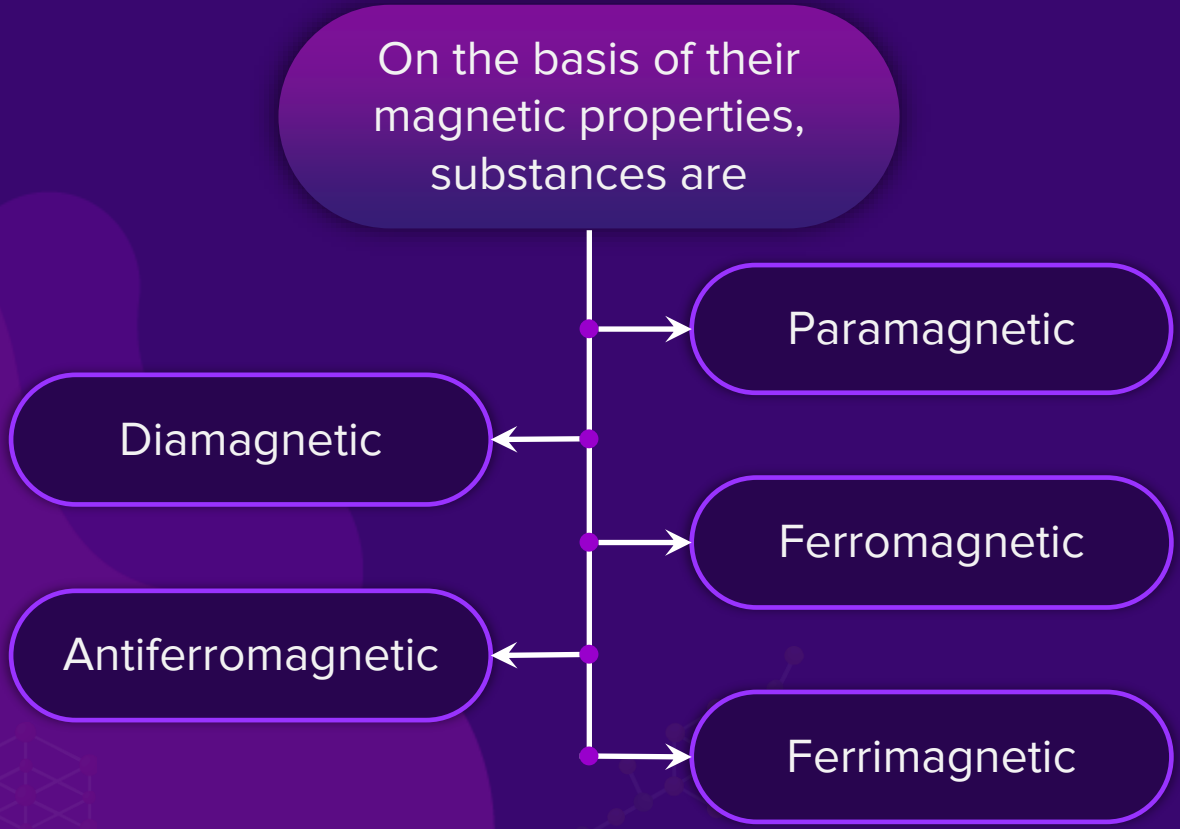


Demonstration of the magnetic moment associated with (a) an orbiting electron and (b) a spinning electron.



Electron moves around nucleus in orbit just as current carrying loop constitute magnetic dipole moment. Electron moving in these orbits also constitute magnetic dipole moment. Besides the orbital motion the electron have spin motion along an axis, this spin also contribute a magnetic moment.

Classification of Substances



Paramagnetic Substances

Substances that are **attracted by the external magnetic field**

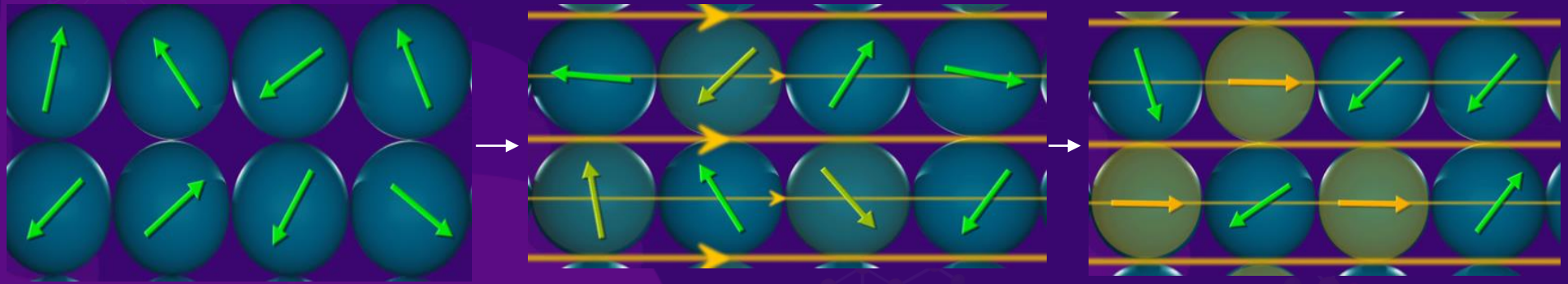
Atoms, ions or molecules containing **unpaired electron** show this property.

Examples

O_2, Cu^{2+}, Fe^{3+} etc. These substances **lost their magnetism** in the **absence** of magnetic field.

Paramagnetic Substances

Atoms of paramagnetic material have unpaired electron in their orbital due to which they have permanent dipole moment. In absence of magnetic field, the magnetic moment of atoms are randomly oriented and net dipole moment such material is zero. When an external magnetic field is applied, the magnetic dipole experiences torque, at same time thermal energy opposes the same, due to opposing factors, only small numbers of dipoles aligned in the direction of magnetic field and the net dipole moment of that material becomes non zero.



Net dipole moment = 0

Magnetic field

Net dipole moment ≠ 0

Diamagnetic Substances

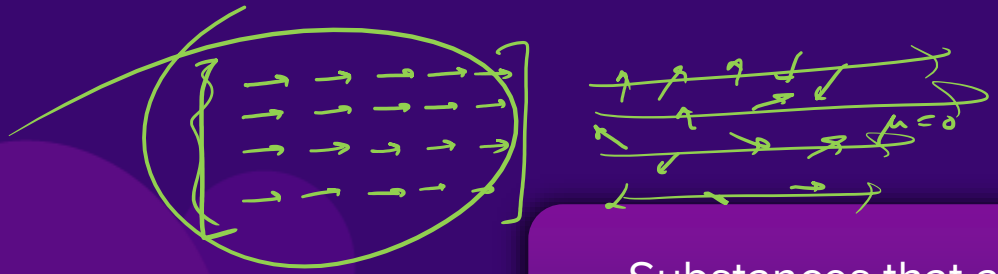
Substances that are very very weakly repelled by magnetic field

They **do not** have **unpaired electrons**.

Examples

Cu^+, TiO_2, NaCl, and C_6H_6

Ferromagnetic Substances

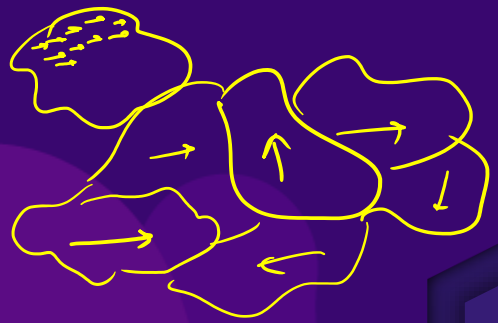


Substances that are **attracted very strongly** by a magnetic field

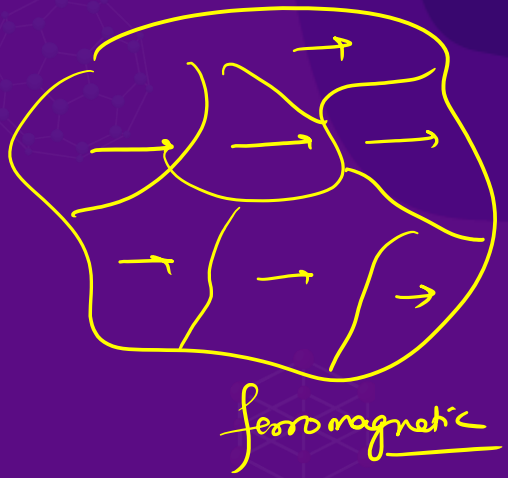
Substances that show **permanent magnetism** even in the **absence** of the magnetic field.

Ferromagnetic Substances

Domain



antiferromagnetic



ferromagnetic

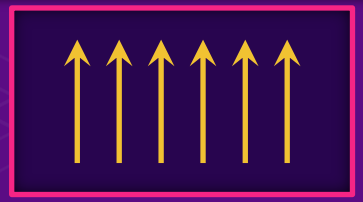
In a solid state, the metal ions of ferromagnetic substances are **grouped** together into **small regions** called domains.

- If domains are randomly oriented then it acts as antiferromagnetic. If all domains are perfectly oriented in one direction then it is **ferromagnetic.**

Ferromagnetic Substances

In an unmagnetised piece of a ferromagnetic substance, the domains are **randomly oriented** and their magnetic moments get **cancelled.**

When the substance is placed in a magnetic field, all **domains get oriented** in the direction of the magnetic field and a **strong magnetic effect** is produced.

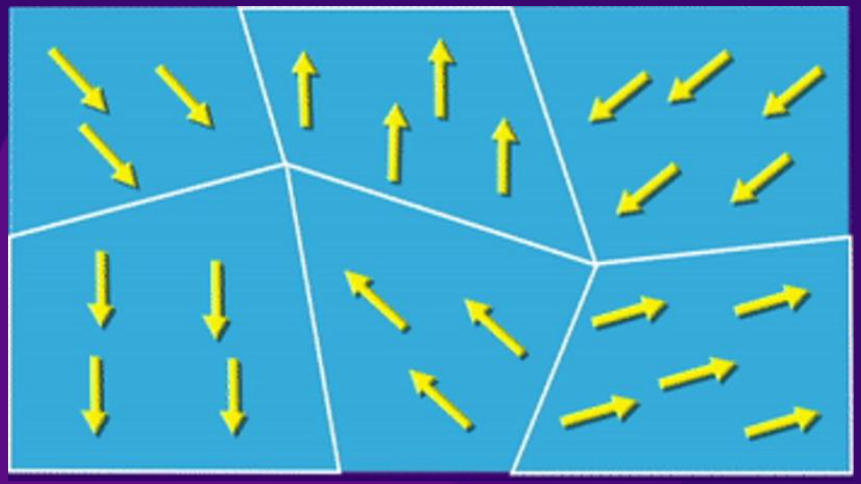


This ordering of domains persist even when the magnetic field is removed & the substance becomes a **permanent magnet**.

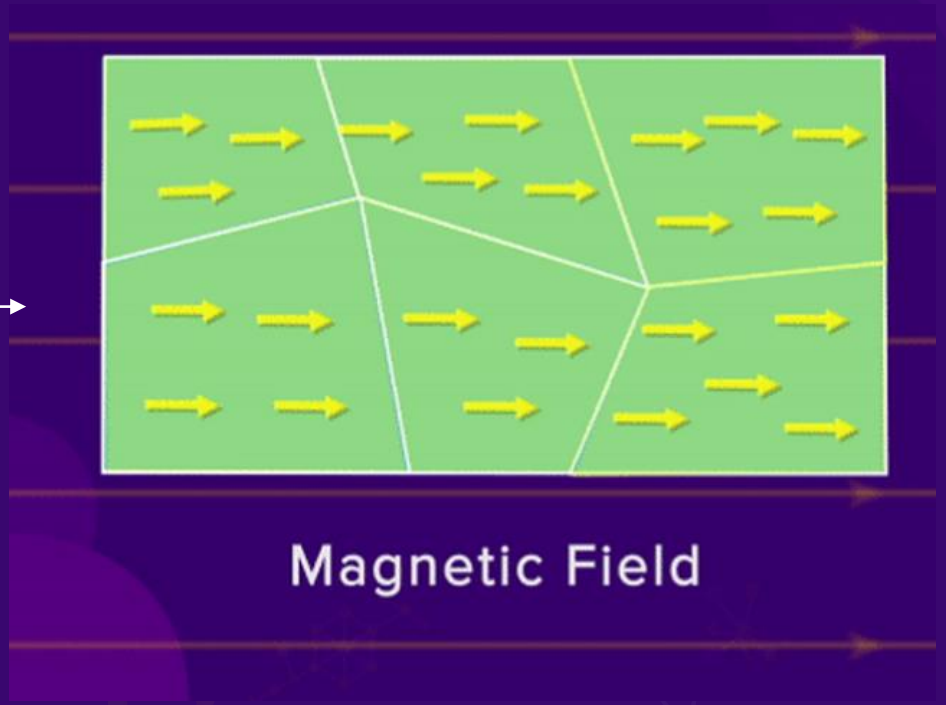
Examples

Fe, Ni, Co, and CrO_2.

Ferromagnetic Substances



Domain



Magnetic Field

Ferromagnetic Substances

In ferromagnetic material, the atoms contains more number of unpaired electron, so more dipole moment as compared to paramagnets.

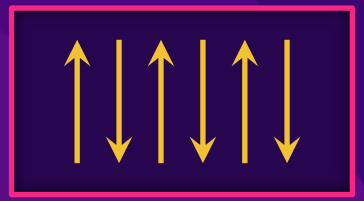
The dipole moment of one electron strongly interact with the dipole moment of neighboring atoms and aligned them in common direction, this small group of atoms with dipole moments in the same direction is known as domain.

A ferromagnetic magnetic material as a whole made up of very large number of such domain, in the absence of magnetic field, the dipole moment of one cancels the dipole moment of other domain, so that net magnetic moment of entire material is zero.

In presence of external magnetic field domain starts aligned on direction of magnetic field. On increasing magnetic field, all domain aligned themselves in given magnetic field direction, and this stage is the ultimate stage of magnetization.

Antiferromagnetic Substances

Substances showing anti-ferromagnetism have domain structure **similar** to ferromagnetic substance, but their domains are **oppositely oriented** and **cancel out** each other's magnetic moment.



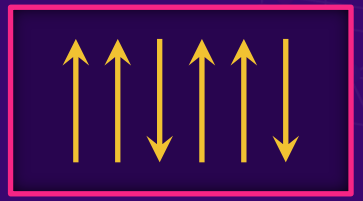
Example

MnO

Ferrimagnetic Substances

Substances in which the magnetic moments of the domains are aligned in **parallel & anti-parallel** directions in **unequal numbers**.

They are **weakly attracted** by magnetic field as compared to ferromagnetic substances.

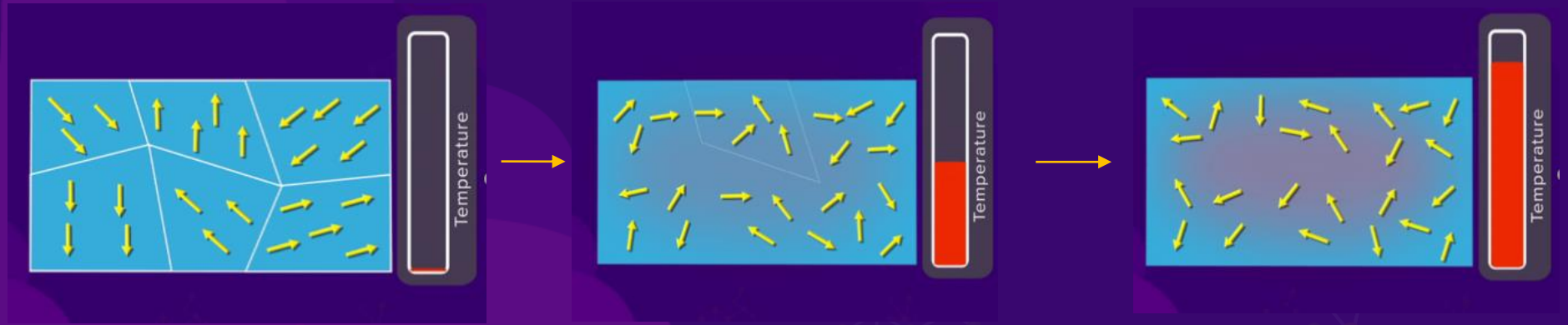


Examples

Fe_3O_4, ferrites like $MgFe_2O_4$ and $ZnFe_2O_4$

Curie Point

When ferromagnetic material is heated, due to thermal energy the dipole moment within the domain start coming out of alignment and become random. The randomization goes on increasing then at particular temperature the domain structures becomes completely destroyed and ferromagnetic material becomes Paramagnetic material, this particular point is known as Curie point



Practice Questions

Which of the following compounds is metallic and ferromagnetic?

BOARDS MAIN

a CrO_2

b VO_2

c MnO_2

d TiO_2

Solution

CrO_2 is metallic and ferromagnetic in nature.

Hence, option (a) is the correct answer.

Which of the following arrangements shows the schematic alignment of magnetic moments of antiferromagnetic substance?

BOARDS MAIN

a

b

c

d

Solution

Option a: It is a type of ferrimagnetic substance.

Option b: It is a type of ferromagnetic substance.

Option c: It is a type of ferrimagnetic substance.

Option d: It is a type of antiferromagnetic substance.

Hence, option (d) is the correct answer.

Which of the following is ferromagnetic?

BOARDS MAIN

a. Cobalt

b. Iron

c. Manganese

d. Nickel

Solution

- Cobalt, iron and nickel are ferromagnetic substances.
- Manganese is an antiferromagnetic substance.

Hence, options (a) , (b) and (d) are the correct answer.

Fe_3O_4 is ferrimagnetic at room temperature but at 850 *K* it becomes:

BOARDS MAIN

a Diamagnetic

b Non-magnetic

c Ferromagnetic

d Paramagnetic

Solution

At higher temperatures, domains of ferrimagnetic, ferromagnetic and antiferromagnetic substances get destroyed and it acts as paramagnetic.

Hence, option (d) is the correct answer.

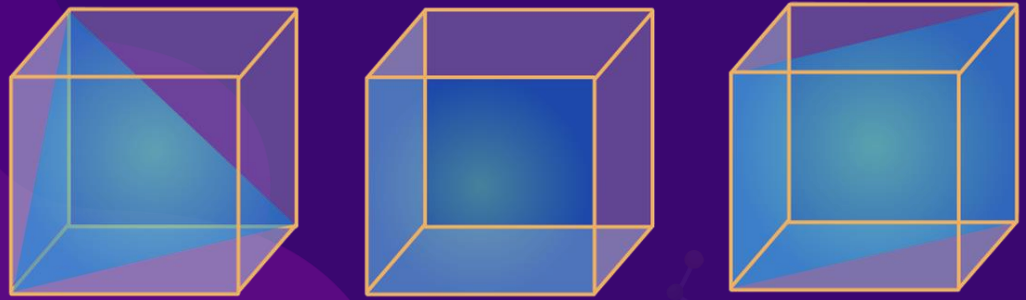
Following three planes (P_1, P_2, P_3) in FCC unit cell are shown: Consider the following statements and choose the correct option that follow:

(i) P_1 contains no voids of three dimensions.

(ii) P_2 contains only octahedral voids.

(iii) P_3 contains both octahedral and tetrahedral voids.

BOARDS MAIN ADVANCED



P_1 P_2 P_3

(a) All are true

(b) Only (i) & (ii) are true

(c) (i) & (iii) are true

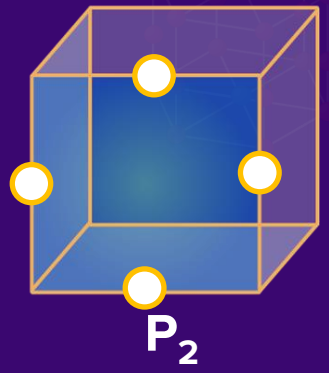
(d) Only (iii) is true

Solution

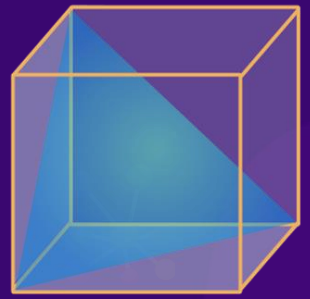
Tetrahedral voids are present at body centred. So, in P_2 we cannot see any tetrahedral voids.

Octahedral voids are present at edge centered. Therefore, we can see that P_2 contains only octahedral voids.

In P_1, there is neither edge centred nor body centered. Also, it does not pass through the mini cubes center.
So, there are neither tetrahedral nor octahedral voids. Hence, P_1 contains no voids of three dimensions.



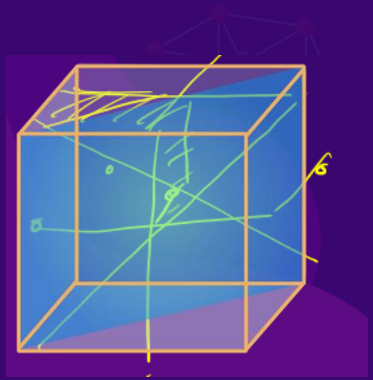
P_2



P_1

For P_3 it is passing through edge centered and body centered. So, there are octahedral voids present.
we can see that it passes through the body diagonal and each body diagonal has 2 tetrahedral voids.
Therefore, P_3 contains both octahedral and tetrahedral voids.

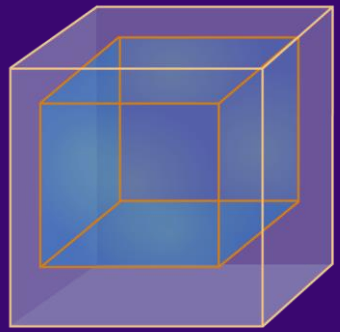
Hence, option (a) is the correct answer.



P_3

In an FCC unit cell, a cube is formed by joining the centres of all the tetrahedral voids to generate a new cube. Then the new cube would contain voids as:

BOARDS MAIN ADVANCED



a. 1 full tetrahedral void and 1 full octahedral void

b. 1 full tetrahedral void only

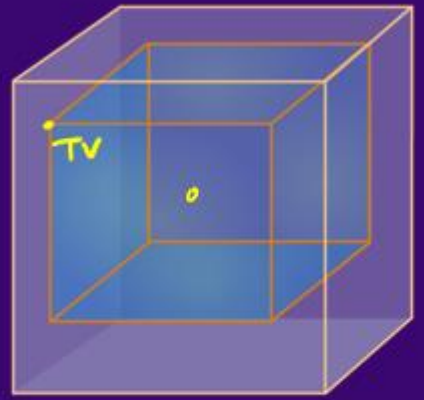
c. 8 full tetrahedral voids and 1 full octahedral void

d. 1 full octahedral void only

Solution

New, tetrahedral voids will be at corners of the cube. Effective number of tetrahedral voids = 1.
Octahedral void will be at the body center.
Therefore, Total octahedral voids = 1.
So, the new cube will have 1 full tetrahedral void and 1 full octahedral void.

Hence, option (a) is the correct answer.



$\frac{1}{8}^{th}$ TV × 8 = 1 TV

Three lines are drawn from a single corner of an **FCC unit cell** to meet the other corner, such that they are found to pass through exactly only **1 octahedral void**, **no voids of any type**, and exactly **2 tetrahedral voids** with **1 octahedral void**. Identify the lines?

BOARDS MAIN

(a) Edge length
(b) Body diagonal
(c) Face diagonal
(d) A line which passes through only 2 face centres of opposite faces

Solution

In face-centered cubic (FCC) atoms are present at **corners and face center.** Octahedral voids are located on edge centers and body center and tetrahedral voids are located on body diagonals. There are 2 tetrahedral voids on the body diagonal at $(¼)^{th}$ of the distance from each corner.

So, if a line joining opposite corners passes through 1 octahedral void only, it must be the edge.
If a line passes no voids of any type on joining two opposite corners it must be face diagonal.
If a line joining the opposite corner passes through 2 tetrahedral and exactly 1 octahedral void only, then it must be body diagonal.

Hence, options (a), (b) and (c) are the correct answer.

In a crystalline solid, having molecular formula A_2B, anions (B) are arranged in cubic close packed lattice and cations (A) are equally distributed between octahedral and tetrahedral voids. (i) What percentage of octahedral voids is occupied? (ii) What percentage of tetrahedral voids is occupied?

Report your answer [(i) – (ii)].

BOARDS MAIN

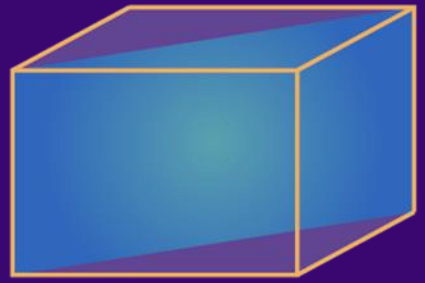
Solution

Number of B anions = 4 [cubic close packed]
Number of octahedral voids = 4
Number of tetrahedral voids = 8
Since the molecular formula is A_2B so number of A cations = 8
Therefore, 4 in tetrahedral and 4 in octahedral voids.

(i) Hence percentage of octahedral void occupied = 100%
(ii) Percentage of tetrahedral void occupied = 50%
[(i) – (ii)] = [100 - 50]% = 50%.

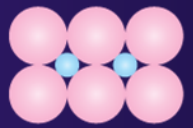
In a solid, S^{2-} ions are packed in FCC lattice. Zn^{2+} occupy half of the tetrahedral voids in an alternating arrangement. Now, if a plane is cut (as shown), then the cross-section would be:

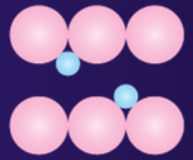
BOARDS MAIN

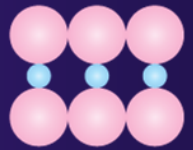


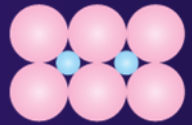
Zn^{2+}

S^{2-}

a 

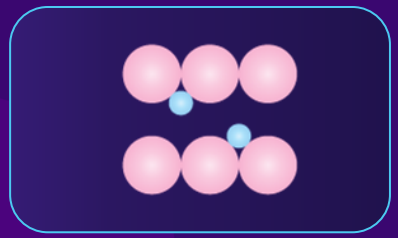
b 

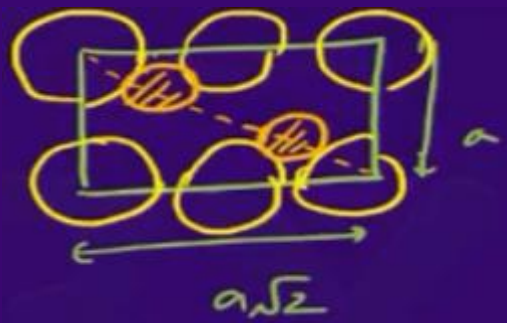
c 

d 

Solution

Given, S^{2-} ion form fcc lattice.
Zn^{2+} ion occupy alternate four tetrahedral void.
Then the cross section is,

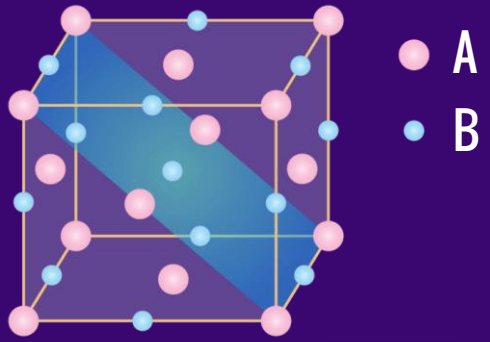




Hence, option (b) is the correct answer.

A crystal is made of particles A and B. A forms FCC packing and B occupies all the octahedral voids. If all the particles along the plane as shown in figure are removed, then, the formula of the crystal would be:

BOARDS MAIN



a. AB

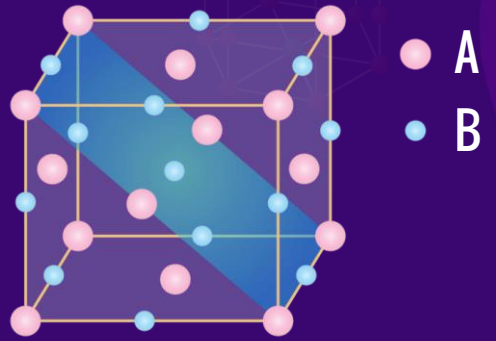
b. A_5B_7

c. A_7B_5

d. None of these

Solution

In fcc, a total of 4 octahedral voids are present. So, it contains 4 A and 4 B atoms but all the particles along the plane as shown in the figure given in the question are removed.



This plane contains (3/2) octahedral void atoms (at body center and 2 at edge center) and (3/2) lattice atoms (2 face centers and 4 corners).

So, the formula will be $A_{\left(4-\frac{3}{2}\right)}B_{\left(4-\frac{3}{2}\right)}$

$= A_{2.5}B_{2.5}$

$= AB.$

Hence, option (a) is the correct answer.

A metal crystallizes in BCC. Find the % fraction of edge length not covered, and also % fraction of edge length covered by atom is:

BOARDS MAIN

Solution

$a\sqrt{3} = 4r \quad \therefore a = \frac{4}{\sqrt{3}}r$

$\% \text{ covered} = \frac{2\pi r^2}{\frac{4}{\sqrt{3}}r^2} \times 100$

$= \frac{\sqrt{3}}{2} \times 100$

$= 86.6\%$

a	10.4%
b	13.4%
c	86.6%
d	89.6%

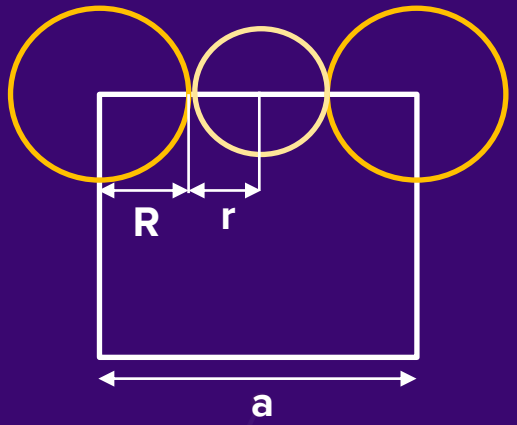
Hence, option (c) is the correct answer.

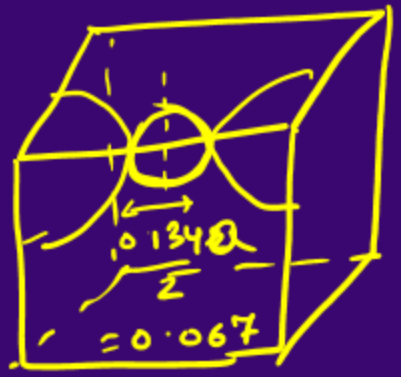
The radius of the largest sphere which fits properly at the centre of the edge of a body centred cubic unit cell is: (Edge length is represented by 'a')

BOARDS MAIN

Solution

From the figure,
a = 2 (R + r)
where,
a = edge length
R = radius of the particle that forms the unit cell
r = radius of the largest sphere which fits properly at the center of the edge of the body centred cubic unit cell.





Solution

Now,

$(a/2) = (R + r)$ ... (1)

$\sqrt{3}a = 4R$ ... (2) (Radius edge length relation for bcc unit cell)

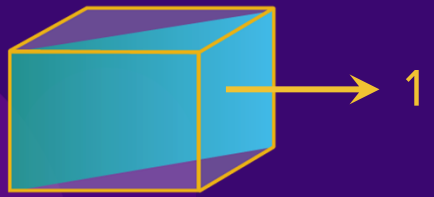
Using (1) & (2) equations ;

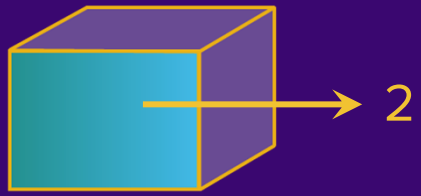
$(a/2) = [(a\sqrt{3}/4) + r]$

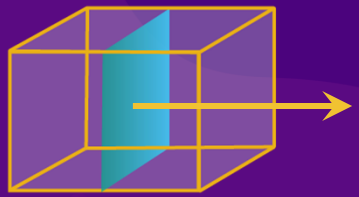
After solving we get (r) = 0.067a.

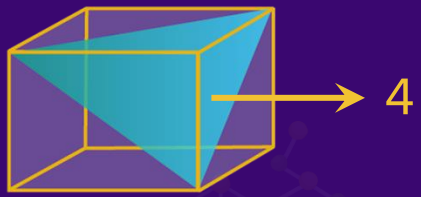
In a BCC-arrangement, which of the marked planes have **maximum spatial density** of atoms?

BOARDS MAIN ADVANCED









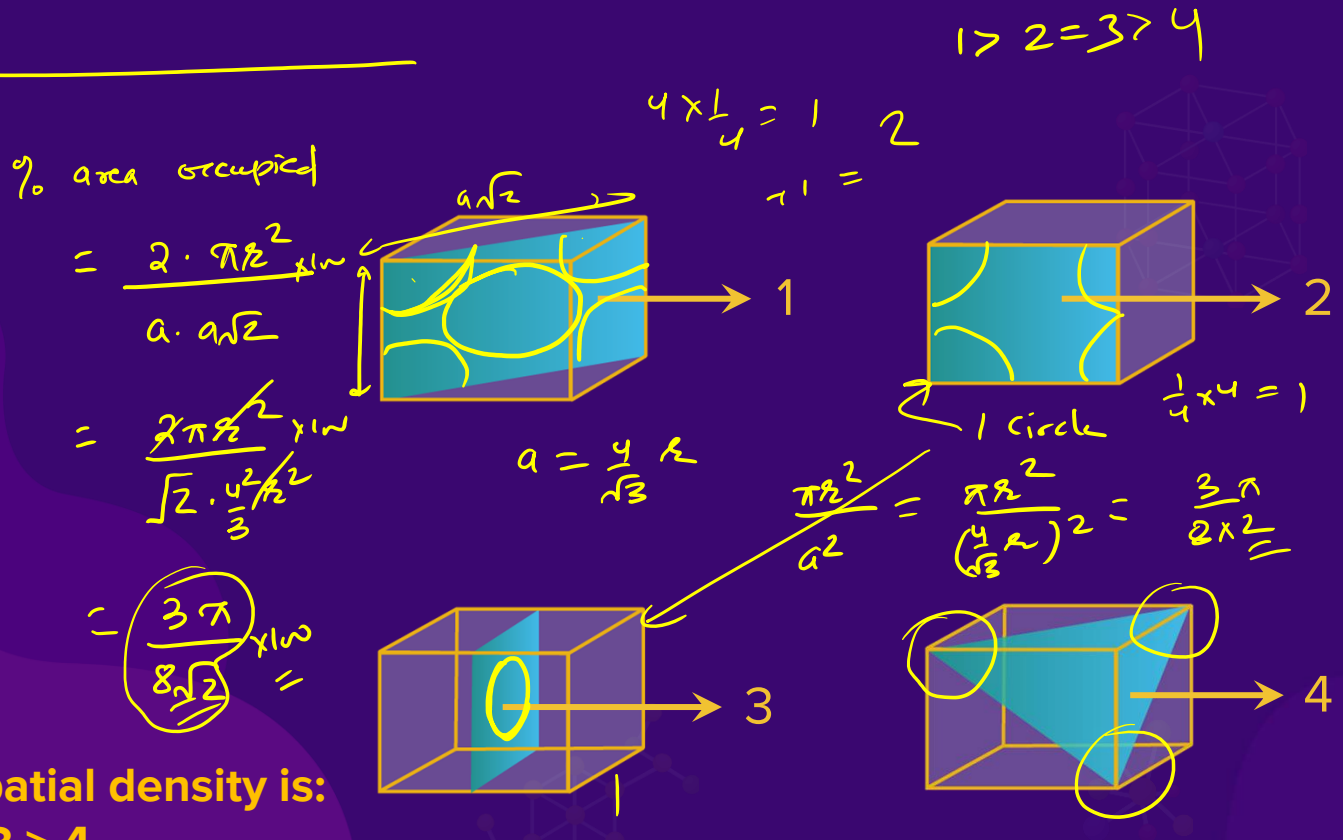
a 1

b 2

c 3

d 4

Solution



So, the order of spatial density is:

1 > 2 = 3 > 4

Hence, option (a) is the correct answer.

Given that interionic distance in Na^+, F^- crystal is 2.31 Å and r_F = 1.36 Å, which of the following predictions will be right?

BOARDS MAIN

(a) $r_{Na^+} / r_{F^-} \simeq 0.7$

(b) Coordination number of Na^+ = Coordination number of F^- = 6

(c) Na^+, F^- will have rock salt type crystal structure

(d) Effective nuclear charge for Na^+ and F^- are equal

Solution

$r_{\oplus} + r_{\ominus} = 2.31 Å$

$- r_{\ominus} = 1.36 Å$

$r_{\oplus} = 0.95 Å$

$\frac{r_{\oplus}}{r_{\ominus}} = \frac{0.95}{1.36} \approx \frac{1}{1.4} \approx 0.707$

$r_{Na^+} / r_{F^-} \simeq 0.7$

- The structure of NaF is the same as Rock salt (NaCl) structure. So, option (c) is correct.
- Rock salt structure has coordination number 6. Therefore, Coordination number of Na^+ = Coordination number of F^- = 6. So, option (b) is correct.
- Na^+& F^- are isoelectronic hence they will have same screening constant (s) but not the effective nuclear charge. So, option (d) is incorrect.

Hence, options (a), (b) and (c) are the correct answer.

Which of the following statement(s) for crystal having Schottky defect is/are correct?

BOARDS MAIN

a

Schottky defect arises due to the absence of cations & anion from positions which they are expected to occupy.

b

The density of crystal having Schottky defect is smaller than that of a perfect crystal.

Which of the following statement(s) for crystal having Schottky defect is/are correct?

c

Schottky defect is more common in covalent compound with higher coordination number.

d

The crystal having schottky defect is electrically neutral as a whole.

Zinc oxide, white in colour at room temperature, acquires yellow colour on heating due to:

BOARDS MAIN

a. Zn being a transition element

b. Paramagnetic nature of the compound

c. Trapping of electrons at the site vacated by oxide ions

d. Both (A) & (B)

Solution

Zinc oxide is colourless at room temperature turns yellow colour on heating because of the trapping of electrons at the vacant site.

Hence, option (c) is the correct answer.

AgCl is crystallised from molten AgCl containing a little $CdCl_2$. The solid obtained will have:

BOARDS MAIN

Solution

When AgCl is doped with $CdCl_2$ Each Cd^{2+} ion replaced 2 Ag^{+} ions to balance the charge.
As a result 1 cationic vacancy is created by each Cd^{2+} ion.
Hence, option (a) is the correct answer.

a. Cationic vacancies equal to number of Cd^{2+} ions incorporated

b. Cationic vacancies equal to double the number of Cd^{2+} ions

c. Anionic vacancies

d. Neither cationic nor anionic vacancies

A mineral of iron contains an oxide containing 72.36% iron by mass and has a density of 5.2 *g/cc*. Its unit cell is cubic with edge length of 839 *pm*. What is the total number of atoms (ions) present in each unit cell? (Atomic mass : Fe : 56 *u*, O : 16 *u*)

BOARDS MAIN

Solution

Let mass of oxide = 100 *g*
Given that iron contains an oxide containing 72.36% iron by mass
Mass of iron = 72.36 *g*
Mass of oxygen = (100 − 72.36) = 27.64 *g*

$$\text{Moles of iron} = \frac{72.36}{56} = 1.292 \text{ moles}$$

$$\text{Moles of oxygen} = \frac{27.64}{16} = 1.727 \text{ moles}$$

$$\text{So, Fe : O} = \frac{72.36 \times 16}{56 \times 27.64}$$

Fe : O = 1 : 1.33
Hence proportion is 1 : 1.33
So, empirical formula is Fe_3O_4

Given, density = 5.2 *g/cc*

$$\text{Formula for density} = \frac{Z \times M}{N_A \times a^3}$$

Mass of Fe_3O_4 = 232 *g*

a = 839 *pm* = 8.39×10^{-8} *cm*

$$\text{Therefore, density} = \frac{Z \times 232}{6.022 \times 10^{23} \times (8.39 \times 10^{-8})^3}$$

$$5.2 = \frac{Z \times 232}{6.022 \times 10^{23} \times (8.39 \times 10^{-8})^3}$$

$$Z = \frac{1848.78}{232}$$

$$Z = 8$$

Therefore, this cube has 8 units of Fe_3O_4.

The total number of atoms (ions) present in each unit cell = (8 × 7) = 56