# The solid state & surface chemistry

**SUBJECTIVE PROBLEMS:**

## Q 1.

The density of mercury is 13.6 g/ml. Calculate approximately the diameter of an atom of mercury assuming that each atom is occupying a cube of edge length equal to the diameter of the mercury atom. **(IIT JEE 1983 – 3 Marks)**

## Q 2.

Sodium metal crystallizes in body centred cubic lattice with the cell edge, a = 4.29Å. What is the redius of sodium atom? **(IIT JEE 1994 – 2 Marks)**

## Q 3.

A metallic element crystallizes into a lattice containing a sequence of layers of ABABAB……. Any packing of spheres leaves out voids in the lattice. What percentage by volume of this lattice is empty space? **(IIT JEE 1996 – 3 Marks)**

## Q 4.

A unit cell of sodium chloride has four formula units. The edge length of the unit cell is 0.564 nm. What is the density of sodium chloride? **(IIT JEE 1997C – 2 Marks)**

## Q 5.

Chromium metal crystallizes with a body centered cubic lattice. The length of the unit cell edge is found to be 287 pm. Calculate the atomic radius. What would be the density of chromium in $g/cm^3$? **(IIT JEE 1997 – 3 Marks)**

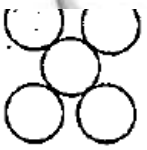
## Q 6.

A metal crystallizes into cubic phases, face centered cubic (BCC), whose unit cell lengths are 3.5 and 3.0 Å, respectively, Calculate the ratio of densities of FCC and BCC.

**(IIT JEE 1999 – 3 Marks)**

## Q 7.

The figures given below show the location of atoms in three crystallographic planes in a FCC lattice. Draw the unit cell for the corresponding structure and identify these planes in your diagram. **(IIT JEE 2000 – 3 Marks)**



**Q 8.**

You are given marbles of diameter 10 mm. They are to be placed such that their centres are lying in a square bound by four lines each of length 40 mm. What will be the arrangements of marbles in a plane so that maximum number of marbles can be placed inside the area? Sketch the diagram and derive expression for the number of molecules per unit area.

**(IIT JEE 2000 – 2 Marks)**

**Q 9.** 1 gm of charcoal adsorbs 100 ml 0.5 M $CH_3COOH$ to form a monolayer, and thereby the molarity of $CH_3COOH$ reduces to 0.49. Calculate the surface area of the charcoal adsorbed by each molecule of acetic acid. Surface area of charcoal = $3.01 * 10^2$ $m^2$/gm.

**(IIT JEE 2003 – 2 Marks)**

**Q 10.**

A compound AB has rock slat type structure. The formula weight of AB is 6.023 Y amu, and the closest A – B distance is $Y^{1/3}$ nm, where Y is an arbitrary number. **(IIT JEE 2004 – 2 Marks)**

(a) Find the density of lattice

(b) If the density of lattice is found to be 20 kg $m^{-3}$, then predict the type of defect.

**Q 11.**

In face centered cubic (fcc) crystal lattice, edge length is 400 pm. Find the diameter of greatest sphere which can be fit into the interstitial void without distortion of lattice.

**(IIT JEE 2005 – 2 Marks)**

**Q 12.**

20% of surface sites are occupied by $N_2$ molecules. The density of surface site is $6.023 * 10^{14}$ $cm^{-2}$ and total surface area is 1000 $cm^2$. The catalyst is heated to 300 K while $N_2$ is completely desorbed into a pressure of 0.001 atm and volume of 2.46 $cm^3$. Find the number of active sites occupied by each $N_2$ molecule. **(IIT JEE 2005 – 4 Marks)**

**Q 13.**

The edge length of unit cell of a metal having molecular weight 75 g/mol is 5 Å which crystallizes in cubic lattice. If the density is 2 g/cc then find the radius of metal atom ($N_A = 6 * 10^{23}$). Give the answer in pm. **(IIT JEE 2006 – 6 Marks)**

# The solid state & surface chemistry-solutions

**SUBJECTIVE PROBLEMS:**

## Sol 1.

Avogadro's number = $6.023 * 10^{23}$

At. wt. of mercury(Hg) = 200

∵ In 1 g of Hg, the total number of atom

= $6.023 *10^{23}/200 = 6.023 *10^{23}/2 *10^{2}$

= $3.0115 *10^{21} = 3.012 * 10^{21}$

∵ Density of Mercury (Hg) = 13.6 g/c.c.

∴ mass of $3.012 * 10^{21}$ atoms = $1/3.012 *10^{21}$

Now volume of 1 atom of mercury (Hg)

= $1/3.012 *10^{21} *13.6$ c.c. = $10^{3} *10/3012 *10^{21} * 136$ c.c.

= $10^{-17}/3012 *136$ c.c. $10^{-17}/409632$ c.c. = $1000000 *10^{-23}/409632$ c.c.

= $2.44 *10^{23}$ c.c.

Since each mercury atom occupies a cube of edge length equal to its diameter, therefore,

Diameter of one Hg atom = $(2.44 * 10^{-23})^{1/3}$ cm

= $(24.4 * 10^{-24})^{1/3}$ cm.

= $2.905 * 10^{-8}$ cm ≡ **2.91 Å**

## Sol 2.

For bcc lattice, (radius), r = √3a/4

Solution

∴ r = √3 *4.29 Å/4 = 1.73 * 4.29 Å/4 = **1.86 Å**

## Sol 3.

For a hcp unit cell, there are 6 atoms per unit cell. If r is the radius of the metal atoms, volume occupied by the metallic

Atoms $6 * 4/3 * \pi * r^3 = 6 * 1.33 * 22/7 * r^3 = 25.08 * r^3$

Geometrically it has been shown that the base area of hcp unit cell

= $6 * √3/4 * 4r^2$ and the height = 4r * √2/3

∴ Volume of the unit cell

= Area * height = $6 * √3/4 * 4r^2 * 4r * \sqrt{\frac{2}{3}} = 33.94\ r^3$

∴ Volume of the empty space of one unit cell

= $33.94\ r^3 – 25.08\ r^3 = 8.86\ r^3$

∴ Percentage void = $8.816\ r^3/33.94\ r^3 * 100$ = **26.1%**

## Sol 4.

Density of NaCl

$= n * \text{at. wt.}/\text{Av. No.} * a^3 = 4 * 58.5/6.023 * 10^{23} * (5.64 * 10^{-8})^3$

**$= 2.16\ g/cm^3$**

## Sol 5.

For bcc lattice, $r = \sqrt{3} * a/4 = \sqrt{3}/4 * 287 =$ **124.27 pm**

Now Density $= n * \text{at. wt.}/V * \text{Av. No.}. = n * \text{at. wt.}/a^3 * \text{Av. No.}$

N = 2 for bcc; $a = 287 * 10^{-10}$ cm

$\therefore$ Density $= 2 * 51.99/(287 * 10^{-10})^3 * 6.023 * 10^{23} =$ **7.30 g/ml**

## Sol 6.

Density in fcc $= n_1 * \text{at.wt.}/V_1 * \text{No.}$

Density in bcc $= n_2 * \text{at.wt.}/V_2 * \text{No.}$

fcc unit cell length = 3.5 Å

bcc unit cell length = 3.0 Å

Density in fcc $= n_1 * \text{at.wt.}/V_1 * \text{Av.No.}$

Density in bcc $= n_2 * \text{at.wt.}/V_2 * \text{Av.No.}$

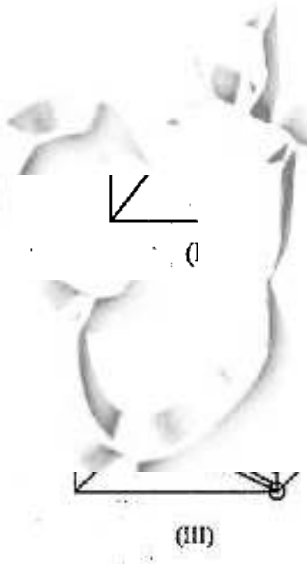
$\therefore D_{fcc}/D_{bcc} = n_1/n_2 * V_2/V_1$

$n_1$ for fcc = 4; Also $V_1 = a^3 = (3.5 * 10^{-8})^3$

$n_2$ for fcc = 2; Also $V_2 = a^3 = (3.0 * 10^{-8})^3$

$\therefore D_{fcc}/D_{bcc} = 4 * (3.0 * 10^{-8})^3/2 * (3.5 * 10^{-8})^3 =$ **1.259**

## Sol 7.



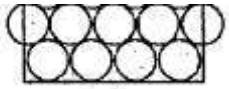
## Sol 8.

The area of square = 4 * 4 = 16 $cm^2$

Again to have the maximum number of spheres the packing must be hcp.

Maximum number of spheres = 14 + 8 = 14 + 4 = 18

full half



Area = 16 $cm^2$

∴ Number of spheres $cm^2$ = 18/16

= 1.126

## Sol 9.

Number of moles of acetic in 100 ml before adding charcoal = 0.05

Number of moles of acetic acid in 100 ml after adding charcoal = 0.049

Number of moles of acetic acid adsorbed on the surface of charcoal = 0.001

Number of molecules of acetic acid adsorbed on the surface of charcoal = 0.001 * 6.02 * $10^{23}$ = 6.02 * $10^{20}$

Surface area of charcoal = 3.01 * $10^2$ $m^2$ (given)

Area occupied by single acetic acid molecule on the surface

of charcoal 3.01 *$10^2$/6.02 * $10^{20}$ = **5 *$10^{-19}$ $m^2$**

## Sol 10.

**(a)** Density of AB = Z *M/$N_0$ * $a^3$

Here, Z = 4 (for fcc), M = 6.023 Y,

A = 2 $Y^{1/3}$ nm = 2 $Y^{1/3}$ * $10^{-9}$ m

Thus,

Density = 4 *6.023/6.023 * $10^{23}$ *(2$Y^{1/3}$ * $10^{-9}$)$^3$

**= 5.0 kg $m^{-3}$**

(b) Since the observed density (20 kg $m^{-3}$) of AB is higher than the calculated (5 kg $m^{-3}$), the compound must have metal excess **defect.** Non-stocheometric degect.

## Sol 11.

For an octahedral void a = 2 (r + R) In fcc lattice the largest void present is octahedral void. If the radius of void sphere is R and of lattice sphere is r. Then,

r = √2 *400/5 = 141.12 pm (a = 400 pm)

applying condition for octahedral void, 2 (r + R) = a

∴ 2 R = a 2r = 400 **–** 2 * 141.12 ∴ Diameter of greatest sphere = **117.16 pm**

## Sol 12.

$P_{N_2}$ = 0.001 atm, T = 300 K, V = 2.46 $cm^2$

∴ Number of $N_2$ molecules

= PV/RT * $N_{AV}$ = 0.001 *2.46 *$10^{-3}$/0.0821 *300 * 6.023 * $10^{23}$

= 6.016 * $10^{16}$

Now total number of surface sites

= Density * Total surface area

= 6.023 * $10^{14}$ * 1000 = 6.023 * $10^{17}$

Sites occupied by $N_2$ molecules = 20/100 * 6.023 * $10^{17}$ = 12.04 * $10^{16}$

∴ No. of sites occupied by each $N_2$ molecule

= 12.04 *$10^{16}$/6.016 * $10^{16}$ = **2**

## Sol 13.

For bcc ; r = √3/2 a;

d = n * M/$N_{AV}$ * $a^3$ or n = d *$N_{AV}$ *$a^3$/M

=> n = 2 *6 *$10^{23}$ (5 *$10^{-8}$)$^3$/75 = 2

Therefore Metal crystallizes in BCC structure and for a BCC lattice √3a = 4r

r = √3/4 a = √3 *5/4 = 2.165 Å = 216.5 pm

so the required answer is **217** pm.