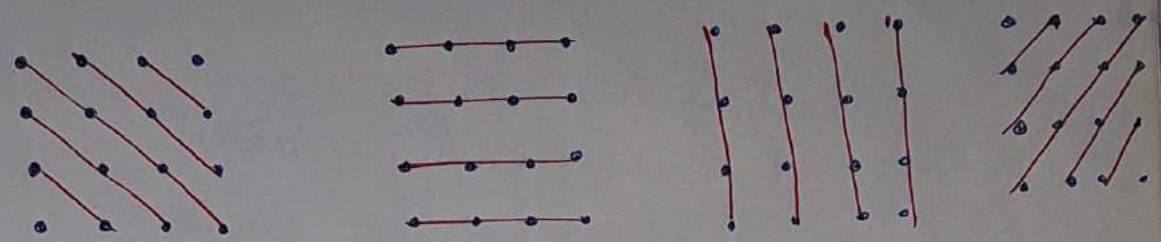
CRYSTAL PLANES & MILLER INDICES

CRYSTAL PLANES

Crystal lattice ~~[illegible]~~ is made-up of an aggregate of a set of ∥ equidistant planes passing through the lattice points, known as lattice planes

For a given lattice, planes can be chosen in different ways. Spacing b/w successive planes is diff for diff set of planes.

Ex



In order to specify a crystal, Miller introduced the concept of Miller Indices of a plane, which is a set of 3 no's. Main property of M.I. is that they are same for all ∥ planes.

How to find Miller Indices

1. Take any atom in crystal as origin & erect co-ordinate axis from origin in the direction of basis vectors. Axis can be primitive or Non-primitive.
2. Choose any plane of set of interest & note its intercept on a, b, c - axes in terms of lattice constants. No intercept of the plane should be at origin. As all ∥ planes are similar, so only consider nearest plane.
3. Take reciprocals of these intercepts & convert fraction into smallest set of integers. Denote those no's by h, k, l known as M.I. of the plane.
4. Representation (h, k, l)
5. Plane ∥ to any of 3 axes → Intercept = ∞ → M.I = 0
6. If plane cuts on -ve axis → M.I = -ve

(7) (h,k,l) do not explain any single plane but a group of ll planes. (nh, nk, nl) is same as (h,k,l) plane

(8) $(h,\bar{k},l)$ → plane cuts y-axis on −ve side

(9) Consider family of planes whose MI differ by permutation of indices or of −ve sign

(h,k,l), $(\bar{h},k,l)$, $(h,\bar{k},l)$, $(h,k,\bar{l})$, $(\bar{h},k,\bar{l})$, $(h,\bar{k},\bar{l})$

or (h,k,l) (k,h,l), (l,h,k)

All these are crystallographically equivalent.

(10) $\{h,k,l\}$ → All six equivalent cube faces.

: (100), (010), (001), $(\bar{1}00)$ $(0\bar{1}0)$, $(00\bar{1})$

(11) $[111]$ → Body-diagonal

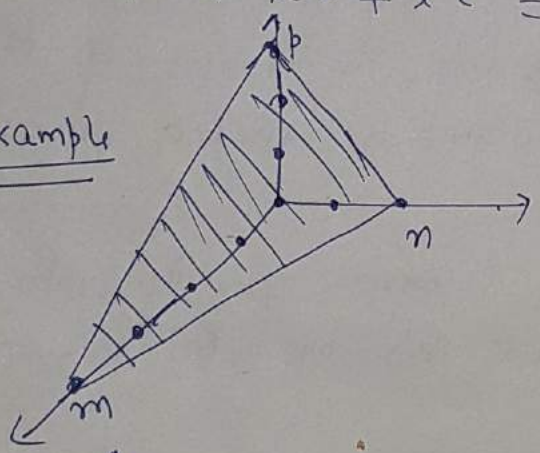
+a-axis → $[100]$	+b axis → $[010]$
−a-axis → $[\bar{1}00]$	−b-axis → $[0\bar{1}0]$

(12) Diagonal of ab face → $[110]$

" " ac " → $[101]$

$h\vec{a} + k\vec{b} + l\vec{c}$ = Vector = $[h,k,l]$

<u>Example</u>



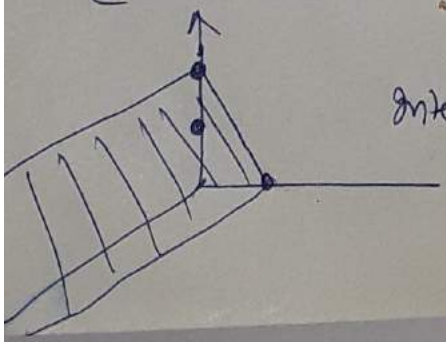
mnp → Plane (Δ)

Cuts axis at → $(2a, 4b, 3c)$

MI → $\left(\frac{1}{2}, \frac{1}{4}, \frac{1}{3}\right)$

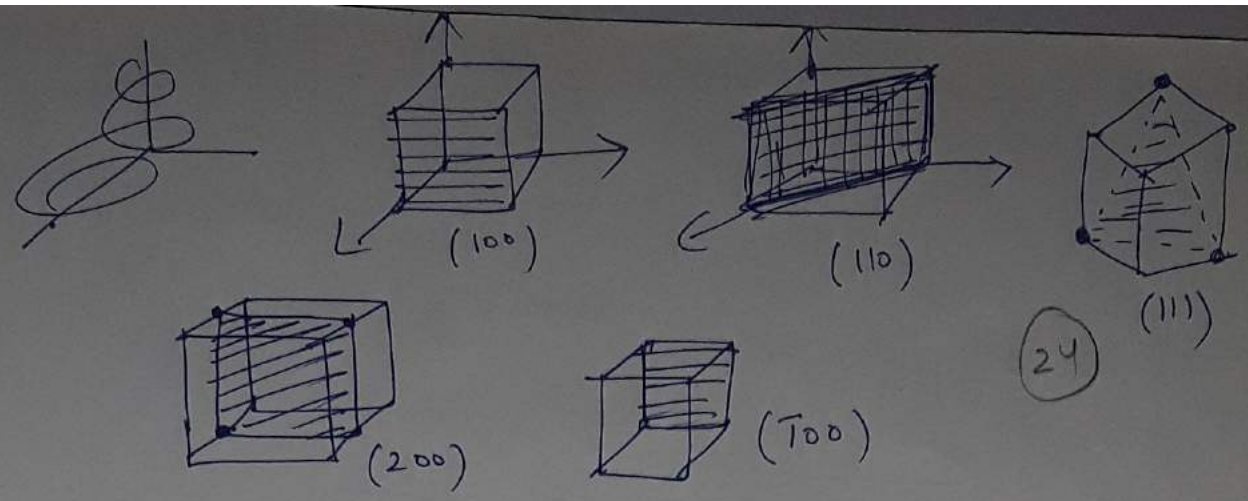
Reduce fraction → $(6, 3, 4)$

(h, k, l)

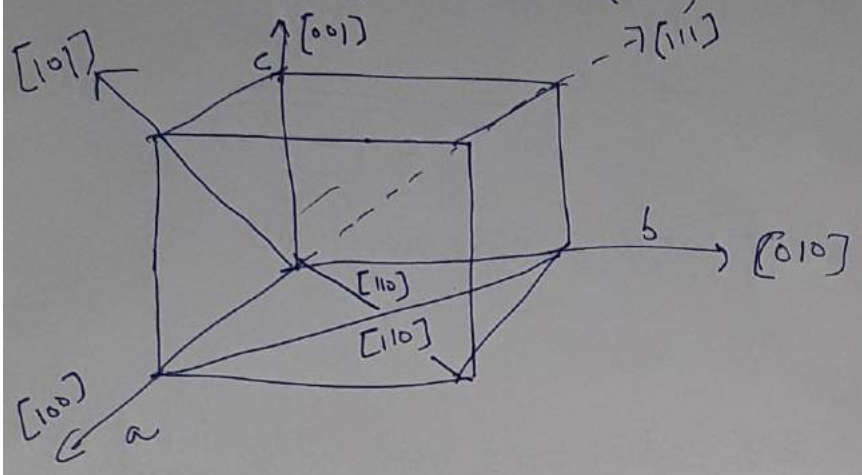


Intercepts ⇒ $(a, \infty, 2c)$

MI ⇒ $\left(\frac{1}{1}, \frac{1}{\infty}, \frac{1}{2}\right) = (2, 0, 1)$



Plane (200) is ∥ to (100)



① Angle b/w any two crystallog. directions [hkl] & [h'k'l']

⇓

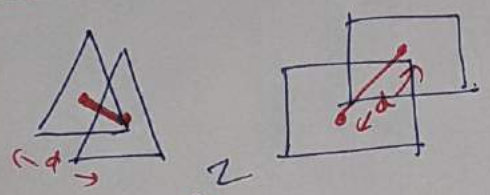
$$\cos\theta = \frac{hh' + kk' + ll'}{\sqrt{h^2+k^2+l^2}\,\sqrt{h'^2+k'^2+l'^2}}$$

② distance d b/w adjacent planes of index nos (hkl)

⇓

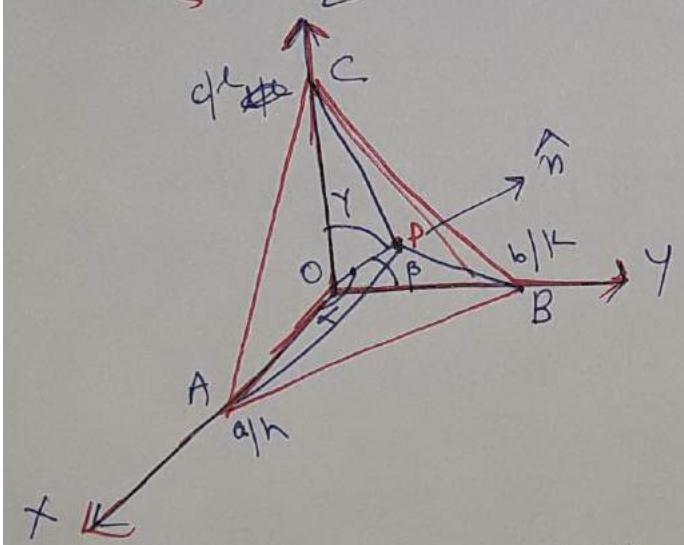
$$d = \frac{a}{\sqrt{h^2+k^2+l^2}}$$

Interplanar Spacing



(hkl) → family of planes

d = distance b/w adjacent planes of this family



let OX, OY, OZ mutually ⊥ to each other.

let reference frame (hkl) passes through origin.

& next plane ∥ to it cuts the intercepts at a/h, b/k, l/c

Drop OP ⊥ to plane from origin

ON = d = ⊥ distance from origin to plane

$d = OP = \frac{a}{h}\cos\alpha = \frac{b}{k}\cos\beta = \frac{c}{l}\cos\gamma$

$\cos\alpha$, $\cos\beta$, $\cos\gamma$ → Direction cosine of OP

$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$

$\therefore$

$$\left(\frac{dh}{a}\right)^2 + \left(\frac{dk}{b}\right)^2 + \left(\frac{dl}{c}\right)^2 = 1$$

(25)

$$d = \left(\sqrt{\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}}\right)^{-1} = \frac{1}{\sqrt{(h/a)^2 + (k/b)^2 + (l/c)^2}}$$

for cubic lattice ⇒ $a = b = c$ → $d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$

* for non-orthogonal lattices above expression can't be calculated.

Q) Show that all planes with low index no's have wide interplanar spacing as compared to high index.

Ans for SC (100 plane) ⇒ $d = \frac{a}{\sqrt{1^2 + 0^2 + 0^2}} = a$

(110) plane ⇒ $d = \frac{a}{\sqrt{2}}$

(111) plane ⇒ $d = a/\sqrt{3}$

Q) For BCC there exists additional planes halfway b/w (100) and (111) planes.

for FCC also b/w (100) & also b/w (110) planes

for FCC $d_{100} = \frac{a}{2}$ $d_{111} = a/\sqrt{3}$ $d_{110} = \frac{a}{2\sqrt{2}}$

Q) Find interplanar distance of planes taking a lattice to a cube $a = b = 2\mathring{A}$, if set of ∥ planes make intercept in ratio $3a : 4b$ on X & Y axes and are ∥ to Z-axis

Ans:

(26)

$ma, nb, pc \rightarrow$ intercept

$$\frac{1}{ma} : \frac{1}{nb} : \frac{1}{pc} = \frac{1}{3a} : \frac{1}{4b} : \frac{1}{0c}$$

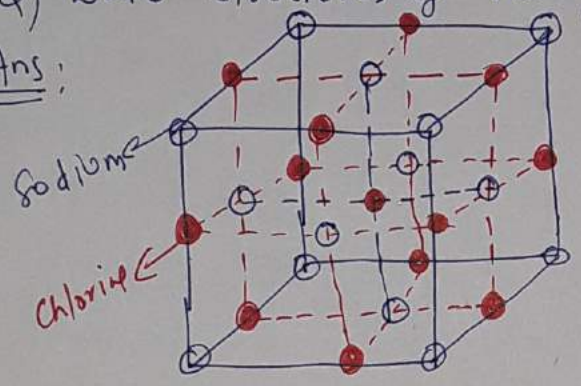
$$= 4 : 3 : 0$$

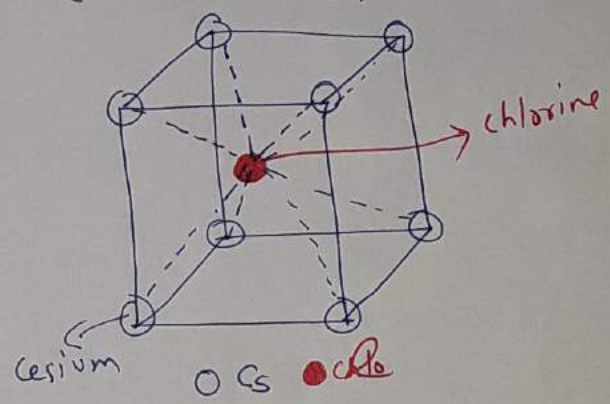
$$h : k : l = 4 : 3 : 0$$

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}} = \frac{2\mathring{A}}{\sqrt{4^2+3^2+0^2}} = \frac{2}{5}\mathring{A} = 0.4\mathring{A}$$

Q) Draw structures of NaCl, CsCl (cesium chloride), diamond.

Ans:





Others having NaCl structure are LiH, KBr, KCl, PbS MnO.

Others having CsCl structures are NH_4Cl, CuZn, AlNi

Na : 000, $\frac{1}{2}\frac{1}{2}0$, $\frac{1}{2}0\frac{1}{2}$, $0\frac{1}{2}\frac{1}{2}$

Cl : $\frac{1}{2}\frac{1}{2}\frac{1}{2}$, $00\frac{1}{2}$, $0\frac{1}{2}0$, $\frac{1}{2}00$

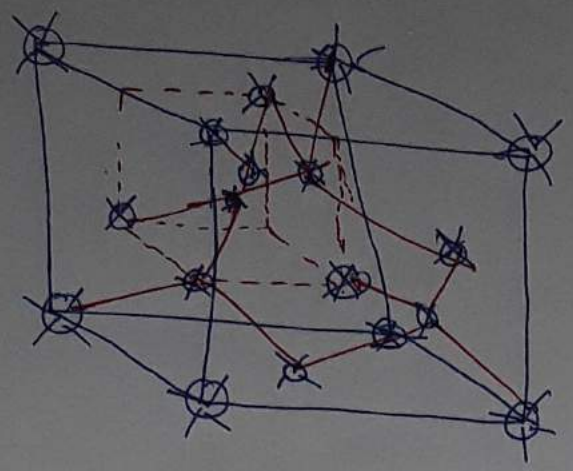
(Positions)

Space lattice is FCC with a basis of one Na atom & one Cl atom sep by half the body diagonal of unit cube

Cs : 000

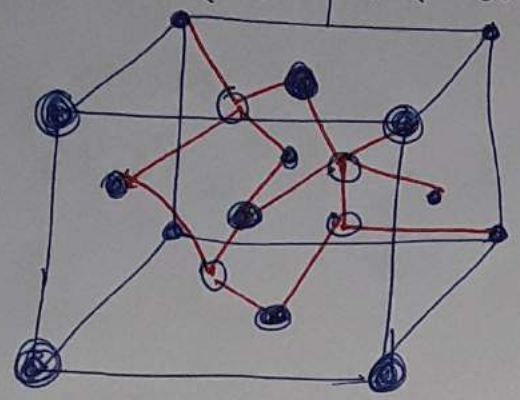
Cl : $\frac{1}{2}\frac{1}{2}\frac{1}{2}$ (Positions)

BCC



Diamond

Cubic Zinc Sulphide or Zinc blend



○ Zn

● S

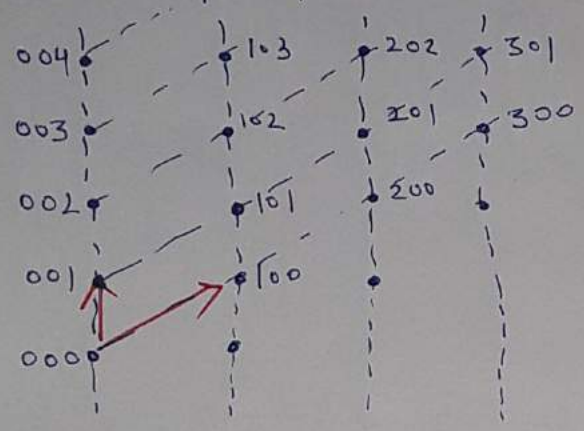
Reciprocal Lattice

Why do we use reciprocal lattice?

→ In a crystal there exists many interpenetrating planes with a variety of orientations and spacings that can diffract a given beam of X-rays. P P. Ewald simplified this by representing such sets of planes, using reciprocal lattice.

In many crystallographic problems we consider the normal to be a set of planes rather than planes themselves. The direction of normal represents orientation of plane.

Length assigned to each normal is ∝ reciprocal of interplanar spacing ~~spacing~~ of that plane, the points at end of ⊥ drawn from a common origin form a lattice known as reciprocal lattice.



How to Construct: (1) Take origin at some arbitrary point.

(2) From a common origin draw a ⊥ to each crystal plane of direct lattice. Direction of ⊥ gives orientation of the plane

(3) Set length of each ⊥ equal to or $2\pi \times \frac{1}{d_{hkl}}$

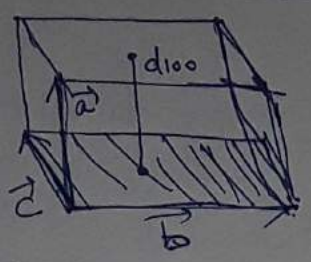
(4) Terminal points of these ⊥ represent the reciprocal lattice bcoz distance in these lattices are reciprocal to those in direct crystal lattice.

Reciprocal lattice vector $= \vec{\sigma}_{hkl} = \frac{1}{\vec{d}_{hkl}}$

It's ∥ to normal to hkl plane

$$\vec{\sigma}_{hkl} = \frac{1}{d_{hkl}} \hat{n}$$

Vector Discussion



$\vec{a}, \vec{b}, \vec{c} \rightarrow$ Primitive Tran. vectors of a direct space lattice.

Vol. of unit cell = Area of base × height of cell.
= area . $\vec{d}_{100}$

29

$$\frac{1}{d_{100}}\hat{n} = \frac{\text{Area}}{\text{Vol. of unit cell}} = \frac{\vec{b}\times\vec{c}}{\vec{a}\cdot(\vec{b}\times\vec{c})}$$

$$\vec{\sigma}_{100}\,\hat{n} = \frac{\vec{b}\times\vec{c}}{\vec{a}\cdot(\vec{b}\times\vec{c})}$$ where $\hat{n}$ = unit vector in direction of $\perp$ to plane of $(\vec{b}, \vec{c})$

$$\boxed{\vec{\sigma}_{100} = \frac{1}{d_{100}}\hat{n} = \frac{\vec{b}\times\vec{c}}{\vec{a}\cdot(\vec{b}\times\vec{c})}} = \vec{a}^*$$

$$\vec{\sigma}_{010} = \frac{\vec{c}\times\vec{a}}{\vec{a}\cdot(\vec{b}\times\vec{c})} = \vec{b}^*$$

$$\vec{\sigma}_{001} = \frac{\vec{a}\times\vec{b}}{\vec{a}\cdot(\vec{b}\times\vec{c})} = \vec{c}^*$$

Properties

(1) $\vec{a}^* \perp \vec{b}$ & $\vec{c}$ $\quad \vec{b}^* \perp \vec{c}$ and $\vec{a}$, $\vec{c}^*$ is $\perp$ to $\vec{a}, \vec{b}$.

(2) $\vec{a}^*\cdot\vec{b} = \vec{a}^*\cdot\vec{c} = \vec{b}^*\cdot\vec{c} = \vec{b}^*\cdot\vec{a} = \vec{c}^*\cdot\vec{a} = \vec{c}^*\cdot\vec{b} = 0$

(3) $\vec{a}^*\cdot\vec{a} = \vec{b}^*\cdot\vec{b} = \vec{c}^*\cdot\vec{c} = 1$ or 2π $\rightarrow$ as $\vec{a}^* = 2\pi\frac{\vec{b}\times\vec{c}}{\vec{a}\cdot\vec{b}\times\vec{c}}$ or $\vec{a}^* = \frac{\vec{b}\times\vec{c}}{\vec{a}\cdot\vec{b}\times\vec{c}}$

(4) $\vec{\sigma}_{200} = 2\vec{\sigma}_{100}$, $\quad \vec{\sigma}_{300} = 3\vec{\sigma}_{100}$

(5) To reach any recipr lattice point hkl, we have to go h units in $\vec{a}^*$, k along $\vec{b}^*$ & l units along $\vec{c}^*$ direction

(6) $\vec{\sigma}_{hkl} = h\vec{a}^* + k\vec{b}^* + l\vec{c}^*$

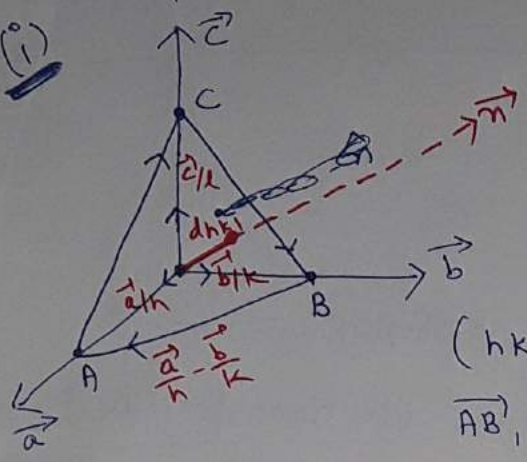
Proof of properties of Reciprocal lattice

(i) The vector $\vec{\sigma}_{hkl}$ is normal to crystal planes (hkl)

(ii) The length of vector $\vec{\sigma}_{hkl} = \frac{1}{d_{hkl}}$

Proof → If we show that a vector lie in (hkl) plane then $\vec{\sigma}_{hkl}$ should also be ⊥ to that vector.

(i)



$$\vec{AB} = \vec{a}/h - \vec{b}/k$$
$$\vec{BC} = \vec{b}/k - \vec{c}/l$$
$$\vec{AC} = \vec{c}/l - \vec{a}/h.$$

(hkl) plane intercepts at $\vec{a}/h$, $\vec{b}/k$, $\vec{c}/l$

$\vec{AB}$, $\vec{BC}$, $\vec{AC}$ are vectors lying in plane (hkl)

Scalar product of $(\vec{a}/h - \vec{b}/k)$ with $\vec{\sigma}_{hkl}$

$$= \left(\frac{\vec{a}}{h} - \frac{\vec{b}}{k}\right) \cdot (h\vec{a}^* + k\vec{b}^* + l\vec{c}^*) = \frac{\vec{a}}{h} \cdot h\vec{a}^* - \frac{\vec{b}}{k} \cdot \vec{b}^* k$$

$$= 1 - 1 = 0$$

Similarly, $(\vec{b}/k - \vec{c}/l) \cdot \vec{\sigma}_{hkl} = 0$

$(\vec{c}/l - \vec{a}/h) \cdot \vec{\sigma}_{hkl} = 0$

$\Rightarrow \vec{\sigma}_{hkl} \perp (\vec{a}/h - \vec{b}/k)$ and $(\vec{b}/k - \vec{c}/l)$

$\Rightarrow \vec{\sigma}_{hkl}$ is ⊥ to vector & normal to plane containing these vector means ⊥ to (hkl) planes

(ii) $\vec{\sigma}_{hkl} = \frac{1}{d_{hkl}}$

let $\hat{n}$ = Unit vector ⊥ to (hkl)

$\hat{n} \parallel \vec{\sigma}_{hkl}$

$$\vec{\sigma}_{hkl} = |\vec{\sigma}_{hkl}|\,\hat{n}$$
$$= h\vec{a}^* + k\vec{b}^* + l\vec{c}^*$$

$$\hat{n} = \frac{h\vec{a}^* + k\vec{b}^* + l\vec{c}^*}{|\vec{\sigma}_{hkl}|}$$

$$d_{hkl} = \left(\frac{a}{h}\right)\cos\alpha \qquad \text{(Distance b/w two planes)}$$

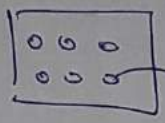
$$= \frac{\vec{a}\cdot\hat{n}}{h} = \frac{\vec{a}\cdot(h\vec{a}^* + k\vec{b}^* + l\vec{c}^*)}{h\,|\vec{G}_{hkl}|}$$

(31)

$$= \frac{\left(\vec{a}\cdot\vec{a}^*\frac{h}{h} + 0 + 0\right)}{|\vec{G}_{hkl}|} = \frac{1}{|\vec{G}_{hkl}|}$$

Significance of Reciprocal lattice

(1) Real lattice



→ Atom/Molecules (sorrounded by e^- in shells)

(2) Atoms/molecules have periodicity therefore e^-s also have periodicity

(3) As temp ↑ the K-value / momentum of e^- also ↑.

(4) Diff b/w K-vectors of two molecules at two lattice points can differ by a reciprocal lattice vector. (This is true for all temp)

(5) e^- inside the crystal interact with ext. rays & undergo a change in momentum, but even after the interaction, change in momentum must be an integral multiple of reciprocal lattice vector.

(6) So scattered rays also undergo a change in momentum which is an integral multiple of reciprocal lattice vector

Thus ΔK → gives a map of reciprocal lattice.

Q) Express direct lattice translation vectors $\vec{a}, \vec{b}, \vec{c}$ in terms of $\vec{a}^*, \vec{b}^*, \vec{c}^*$ reciprocal lattice vectors.

Ans: Consider $\vec{a}^* \times \vec{b}^* = \frac{2\pi(\vec{b}\times\vec{c})}{(\vec{a}\cdot\vec{b}\times\vec{c})} \times \frac{2\pi(\vec{c}\times\vec{a})}{(\vec{a}\cdot\vec{b}\times\vec{c})}$

Volume of lattice $= \vec{a}\cdot(\vec{b}\times\vec{c})$

$$\vec{a}^* \times \vec{b}^* = \frac{(2\pi)^2}{(\vec{a}\cdot\vec{b}\times\vec{c})^2} (\vec{b}\times\vec{c}) \times (\vec{c}\times\vec{a})$$

$$= \left(\frac{2\pi}{V}\right)^2 \left[\vec{c}\left(\vec{a}\cdot(\vec{b}\times\vec{c})\right) - \vec{a}\left((\vec{b}\times\vec{c})\cdot\vec{c}\right)\right]$$

$$= \left(\frac{2\pi}{V}\right)^2 \left[\vec{c}\, V - \vec{a}\cdot 0\right] \qquad \left(\begin{array}{l}\text{bcoz}\\ (b\times c)\cdot c = 0\end{array}\right)$$

$$= \left(\frac{2\pi}{V}\right)^2 \vec{c}\, V = \frac{(2\pi)^2}{V}\vec{c}$$

$$\boxed{\vec{c} = \frac{V}{(2\pi)^2}\left(\vec{a}^* \times \vec{b}^*\right)} \longrightarrow eq\,(1)$$

<u>Now volume of unit cell in reciprocal lattice</u>

$$(\vec{a}^* \times \vec{b}^*)\cdot\vec{c}^* = \frac{(2\pi)^2}{V}\cdot\vec{c}\cdot \quad \vec{c}^*$$

$$= \frac{(2\pi)^2}{V}\vec{c}\cdot\frac{2\pi}{V}(\vec{a}\times\vec{b}) = \frac{(2\pi)^3}{V^2}\vec{c}\cdot(\vec{a}\times\vec{b})$$

$$= \frac{(2\pi)^3}{V^2}\cdot\left((\vec{a}\times\vec{b})\cdot\vec{c}\right) \longrightarrow \text{dot can be exchanged}$$

$$= \frac{(2\pi)^3}{V^2}\times V = \frac{(2\pi)^3}{V}$$

$$\frac{1}{(\vec{a}^* \times \vec{b}^*)\cdot\vec{c}^*} = \frac{V}{(2\pi)^2}(2\pi)$$

$$\boxed{\frac{2\pi}{(\vec{a}^* \times \vec{b}^*)\cdot\vec{c}^*} = \frac{V}{(2\pi)^2}} \longrightarrow eq\,(2)$$

Compare (1) & (2) we get

$$\frac{\vec{c}}{(\vec{a}^* \times \vec{b}^*)} = \frac{2\pi}{(\vec{a}^* \times \vec{b}^*)\cdot\vec{c}^*}$$

$$\Rightarrow \vec{c} = \frac{2\pi(\vec{a}^* \times \vec{b}^*)}{(\vec{a}^* \times \vec{b}^*)\cdot \vec{c}^*} = \frac{2\pi(\vec{a}^* \times \vec{b}^*)}{\vec{a}^*\cdot(\vec{b}^* \times \vec{c}^*)}$$

33

Similarly $\vec{a} = \frac{2\pi(\vec{b}^* \times \vec{c}^*)}{(\vec{a}^* \times \vec{b}^*)\cdot \vec{c}^*} = \frac{2\pi(\vec{b}^* \times \vec{c}^*)}{\vec{a}^*\cdot(\vec{b}^* \times \vec{c}^*)}$

$$\vec{b} = \frac{2\pi(\vec{c}^* \times \vec{a}^*)}{(\vec{a}^* \times \vec{b}^*)\cdot \vec{c}^*} = \frac{2\pi(\vec{c}^* \times \vec{a}^*)}{\vec{a}^*\cdot(\vec{b}^* \times \vec{c}^*)}$$

Property of Scalar triple product

$a\cdot(b\times c) = b\cdot(c\times a)$
$= c\cdot(a\times b)$

Q) Express the relation b/w volumes of unit cell in direct & reciprocal lattice.

Ans: $\vec{a}^*\cdot(\vec{b}^*\times\vec{c}^*)$ = Vol. in reciprocal lattice

$$= \left[\frac{2\pi(\vec{b}\times\vec{c})}{\vec{a}\cdot(\vec{b}\times\vec{c})}\right]\cdot\left[\frac{2\pi(\vec{c}\times\vec{a})}{\vec{a}\cdot(\vec{b}\times\vec{c})} \times \frac{2\pi(\vec{a}\times\vec{b})}{\vec{a}\cdot(\vec{b}\times\vec{c})}\right]$$

$$= \left(\frac{2\pi}{V}\right)^3 (\vec{b}\times\vec{c})\cdot\left[(\vec{c}\times\vec{a})\times(\vec{a}\times\vec{b})\right]$$

$$= \left(\frac{2\pi}{V}\right)^3 (\vec{b}\times\vec{c})\cdot\left[\{\vec{c}\cdot\vec{a}\times\vec{b}\}a - \{\vec{c}\cdot\underbrace{(\vec{a}\times\vec{a})}_{0}\}\vec{b}\right]$$

$$= \left(\frac{2\pi}{V}\right)^3 (\vec{b}\times\vec{c})\cdot\left[\underbrace{(\vec{c}\cdot\vec{a}\times\vec{b})}_{V}a\right]$$

$$= \left(\frac{2\pi}{V}\right)^3 \underbrace{(\vec{b}\times\vec{c})\cdot a}_{V}\, V$$

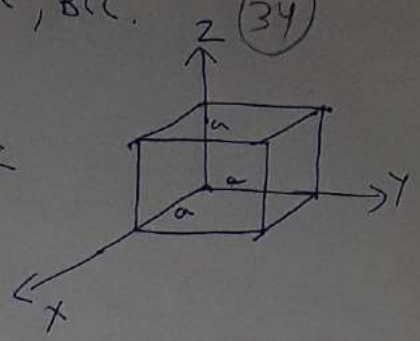
$$= \frac{(2\pi)^3}{V} = \frac{8\pi^3}{\text{Vol. of unit cell in direct lattice}}$$

$$\boxed{V_{Recip} = \frac{8\pi^3}{V_{Direct\ latti}}}$$

Q) Draw & explain reciprocal lattice to SC, FCC, BCC.

Ans

SC : $\vec{a} = a\hat{i}$, $\vec{b} = a\hat{j}$, $\vec{c} = a\hat{k}$



Vol. of cell $= \vec{a}\cdot\vec{b}\times\vec{c} = a^3(\hat{i}\cdot\hat{j}\times\hat{k})$

$V_{SC} = a^3 \cdot 1 = a^3$

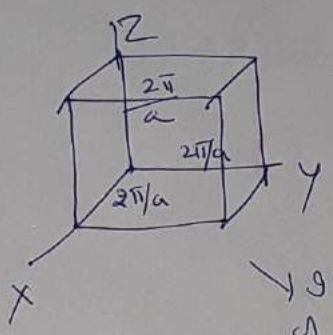
Reciprocal lattice $\Rightarrow$ $\vec{a}^* = \dfrac{2\pi(\vec{b}\times\vec{c})}{\vec{a}\cdot(\vec{b}\times\vec{c})} = \dfrac{2\pi(a\hat{j}\times a\hat{k})}{a^3}$

$= \dfrac{2\pi a^2}{a^3}(\hat{j}\times\hat{k}) = \dfrac{2\pi}{a}\hat{i}$

$\vec{b}^* = \dfrac{2\pi}{a^3}(\vec{c}\times\vec{a}) = \dfrac{2\pi}{a^3}(a\hat{k}\times a\hat{i}) = \dfrac{2\pi}{a}\hat{j}$

$\vec{c}^* = \dfrac{2\pi}{a}\hat{k}$

Reciprocal of SC lattice =



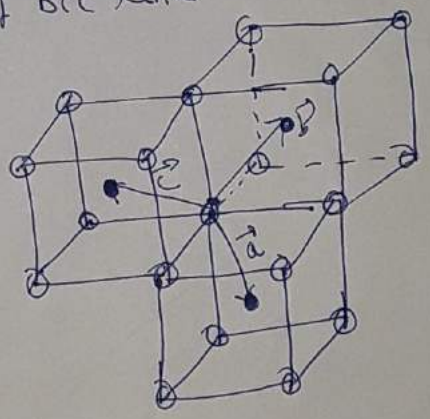
It is also SC lattice of side $= 2\pi/a$

BCC Primitive Translational vectors of BCC lattice

$\vec{a} = \dfrac{a}{2}(\hat{i}+\hat{j}-\hat{k})$

$\vec{b} = \dfrac{a}{2}(-\hat{i}+\hat{j}+\hat{k})$

$\vec{c} = \dfrac{a}{2}(\hat{i}-\hat{j}+\hat{k})$



Volume $= \vec{a}\cdot(\vec{b}\times\vec{c})$

$= \dfrac{a^3}{8}\left[(\hat{i}+\hat{j}-\hat{k})\cdot\{(-\hat{i}+\hat{j}+\hat{k})\times(\hat{i}-\hat{j}+\hat{k})\}\right]$

$V_{BCC} = \dfrac{a^3}{8}\times(4) = \dfrac{a^3}{2}$

$$\vec{a}^* = \frac{2\pi}{V}(\vec{b}\times\vec{c}) = \frac{2\pi}{a^3/2}\left[\frac{a}{2}(-\hat{i}+\hat{j}+\hat{k}) \times \frac{a}{2}(\hat{i}-\hat{j}+\hat{k})\right]$$

$$= \frac{2\pi}{\frac{a^3}{2}} \times \frac{a^2}{4}\left[\hat{i}+\hat{j}\right]\times 2 = \frac{2\pi}{a}(\hat{i}+\hat{j})$$ 35

$\Rightarrow$

$$\vec{a}^* = \frac{2\pi}{a}(\hat{i}+\hat{j})$$

$$\vec{b}^* = \frac{2\pi}{a}(\hat{j}+\hat{k})$$

$$\vec{c}^* = \frac{2\pi}{a}(\hat{i}+\hat{k})$$

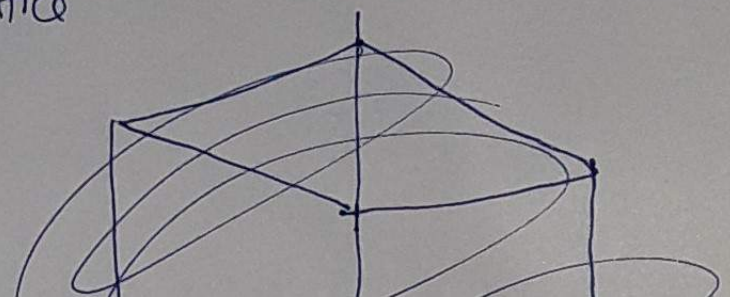
FCC

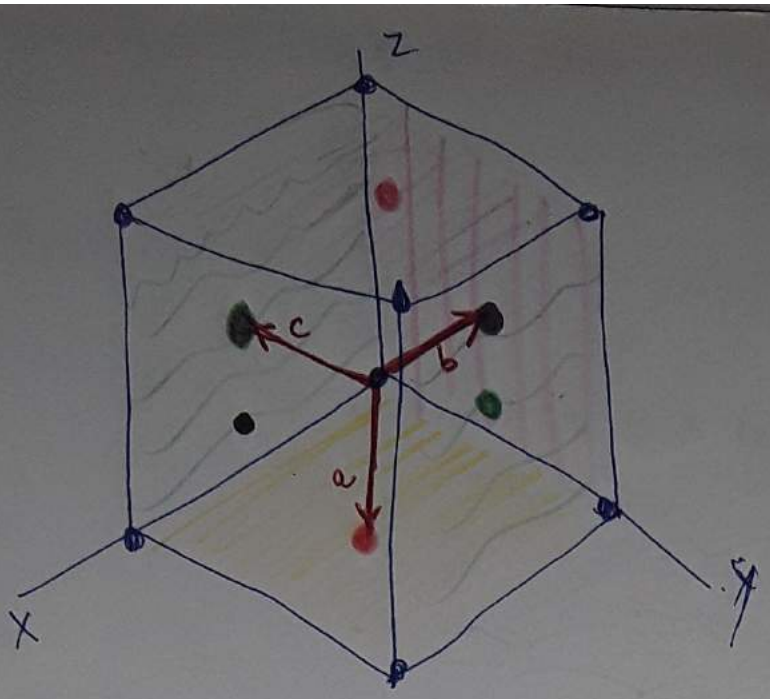
$$\vec{a} = \frac{a}{2}(\hat{i}+\hat{j})$$

$$\vec{b} = \frac{a}{2}(\hat{j}+\hat{k})$$

$$\vec{c} = \frac{a}{2}(\hat{k}+\hat{i})$$

$\rightarrow$ Primitive Translational vector of FCC lattice





$$V = \vec{a}\cdot(\vec{b}\times\vec{c})$$

$$= \frac{a^3}{8}\left[(\hat{i}+\hat{j})\cdot\left\{(\hat{j}+\hat{k})\times(\hat{k}+\hat{i})\right\}\right]$$

$$= \frac{a^3}{8}(1+1) = \frac{a^3}{4}$$

Reciprocal Vectors $\Rightarrow$ $\vec{a}^* = \frac{2\pi}{V}(\vec{b}\times\vec{c}) = \frac{2\pi}{(1/4)a^3}\left[\frac{a}{2}(\hat{j}+\hat{k})\times\frac{a}{2}(\hat{k}+\hat{i})\right]$

$$= \frac{2\pi}{a}(\hat{i}+\hat{j}-\hat{k})$$

$$\vec{b}^* = \frac{2\pi}{a}(-\hat{i}+\hat{j}-\hat{k})$$

$$\vec{c}^* = \frac{2\pi}{a}(\hat{i}-\hat{j}+\hat{k})$$

* BCC is reciprocal of FCC & vice-versa.