# Chapter 1

**Prob. 1.1**

*Which semiconductor in Table 1-1 has the largest $E_g$? the smallest? What is the corresponding $\lambda$? How is the column III component related to $E_g$?*

largest $E_g$ : ZnS, 3.6 eV.

$$\lambda = \frac{1.24}{3.6} = 0.344\mu m$$

smallest $E_g$ : InSb, 0.18 eV.

$$\lambda = 6.89\mu m$$

Note Al compounds have larger $E_g$ than the corresponding Ga compounds, which are larger than In compounds.

**Prob. 1.2**

*Here we need to calculate the maximum packing fraction, treating the atoms as hard spheres.*

Nearest atoms are at a separation $\frac{1}{2}\times\sqrt{(5\times\sqrt{2})^2+5^2} = \mathbf{4.330Å}$

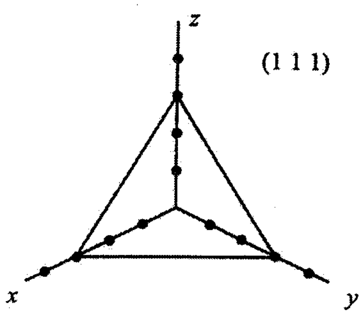
Radius of each atom $= \frac{1}{2}\times 4.330Å = \mathbf{2.165Å}$

Volume of each atom $= \frac{4}{3}\pi(2.165)^3 = \mathbf{42.5Å^3}$

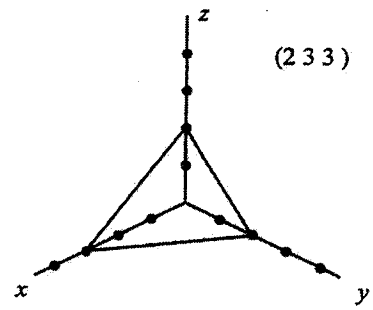
Number of atoms per cube $= 1 + 8\times\frac{1}{8} = \mathbf{2}$

Packing fraction $= \frac{42.5 \times 2}{(5)^3} = \mathbf{68\%}$

**Prob. 1.3**
*(a) Label planes:*

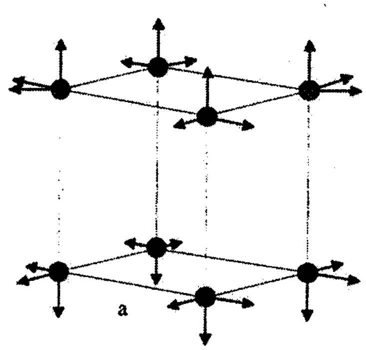



| x | y | z |
|---|---|---|
| 3 | 3 | 3 |
| 1/3 | 1/3 | 1/3 |
| 1 | 1 | 1 |

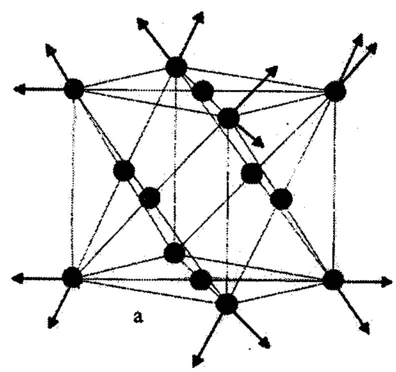



| x | y | z |
|---|---|---|
| 3 | 2 | 2 |
| 1/3 | 1/2 | 1/2 |
| 2 | 3 | 3 |

*(b) Draw equivalent directions in a cube*

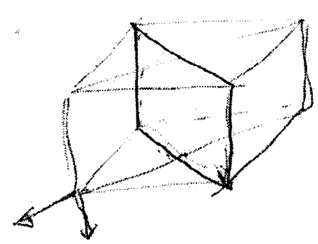



<1 0 0> all edges




<1 1 0> all face diagonals

(Need not show atoms)





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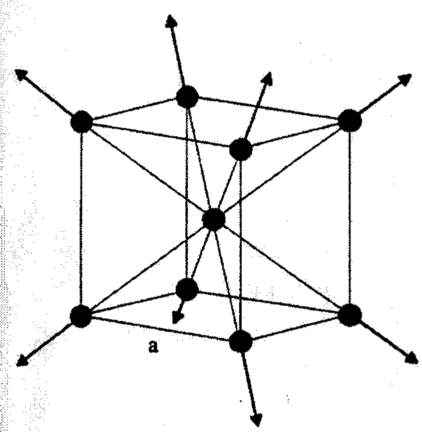
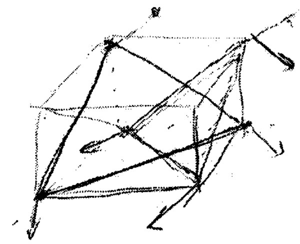


<1 1 1> all body diagonals

**Prob. 1.4**

***We need to calculate the volume density of Si, its density on the (110) plane and the distance between two adjacent (111) planes.***

~~Si FCC lattice~~ with ~~basis of 2 atoms~~

Number of atoms per cube $= \left(8\times\frac{1}{8}+\frac{1}{2}\times 6\right)\times 2 = 8$ ✓

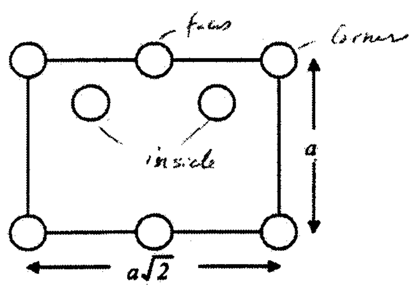
Diamond Lattice

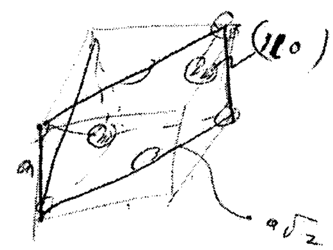
$8(\frac{1}{8}) + 6(\frac{1}{2}) + 4 = 8$

corner face inside atoms

Density $= \frac{8.}{(5.43\times10^{-8})^3} = \mathbf{5.00\times10^{22}\,cm^{-3}}$ ✓

On the (110) plane we have 4 atoms on corners, 2 on the top and bottom planes, and 2 interior (see Fig. 1-a). ✓




$(\frac{1}{4})4 + \frac{1}{2}(2) + 2 = 4$

$(110)$ plane : $\dfrac{4\times\frac{1}{4}+\frac{1}{2}\times 2+2}{(5.43\times10^{-8})(\sqrt{2}\times5.43\times10^{-8})} = \mathbf{9.59\times10^{14}\,cm^{-2}}$

Basis of Si crystal at 0 and $\frac{a}{4},\frac{a}{4},\frac{a}{4}$ which is along $[111]$.

( h k l )

Distance $= \sqrt{3}\left(\frac{a}{4}\right) = \mathbf{2.39\text{Å}}$.

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

**Prob. 1.5**

***Using the hard-sphere model, find the lattice constant of InSb, the volume of the primitive cell and the atomic density on the (110) plane.***

$$\frac{\sqrt{3}a}{4} = 1.44+1.36 = 2.8\text{Å}$$

$$a = 6.47\text{Å}$$

In FCC, unit cell has 4 lattice points. Therefore, volume of primitive cell $= \frac{a^3}{4} = 67.7\text{Å}^3$

Area of $(110)$ plane $= \sqrt{2}a^2$

Density of In atoms $= \dfrac{4\times\frac{1}{4}+2\times\frac{1}{2}}{\sqrt{2}a^2} = \dfrac{\sqrt{2}}{a^2} = \mathbf{3.37\times10^{14}\ cm^{-2}}$

Same number of Sb atoms $= \mathbf{3.37\times10^{14}\ cm^{-2}}$



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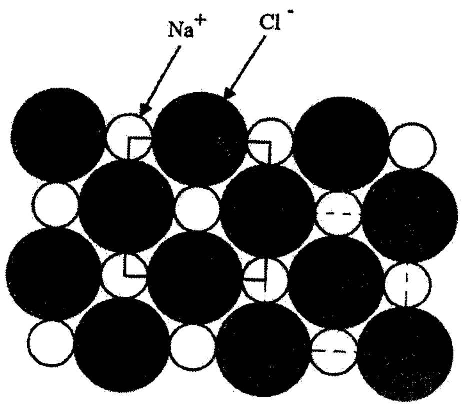
**Prob. 1.6**
*Draw NaCl lattice (1 0 0) and unit cell.*




Two possible unit cells are shown, with either $Na^+$ or $Cl^-$ at the corners.



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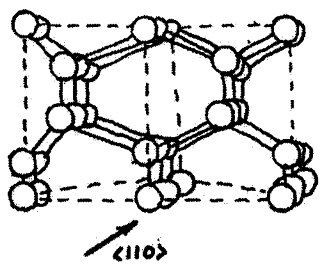
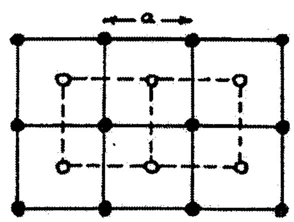
Prob. 1.7

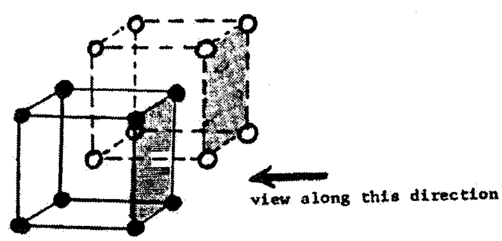



This view is tilted slightly from ⟨110⟩ to show the alignment of atoms. The open channels are hexagonal along this direction.

Prob. 1.8




The shaded points are one sc lattice; the open points are the interpenetrating sc, located a/2 behind the plane of the front shaded points.

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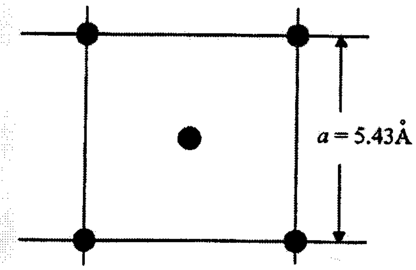
**Prob. 1.9**

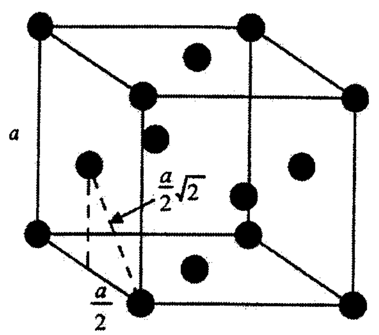
*(a) Find the number of Si atoms/cm² on the surface of a (1 0 0) oriented Si wafer.*




Each $a^2$ has $1 + \frac{1}{4}(4) = 2$ atoms on the surface.

$$\frac{2 \text{ atoms/cell}}{(5.43\times10^{-8})^2 \text{cm}^2/\text{cell}} = \mathbf{6.78\times10^{14} cm^{-2}}$$

*(b) What is the distance (in Å) between nearest In neighbors in InP?*




In atoms are in an fcc sublattice with $a = 5.87\text{Å}$, nearest neighbors are

$$\frac{a}{2}\sqrt{2} = \frac{5.87}{2}\sqrt{2} = \mathbf{4.15Å}$$



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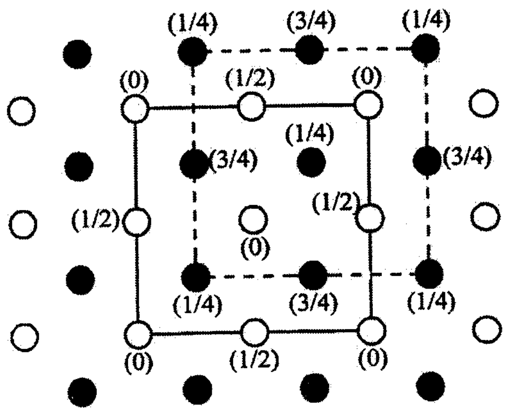
**Prob. 1.10**
*Find NaCl density.*
*$Na^+$: atomic wt. 23, radius 1 Å. $Cl^-$: atomic weight 35.5, radius 1.8 Å.*

The unit cell contains ½ Na and ½ Cl atoms. Using the hard sphere approximation, $a = 2.8$Å.

$$\text{density} = \frac{\frac{1}{2}(23+35.5)/(6.02\times10^{23})}{(2.8\times10^{-8})^3} = \mathbf{2.2\ g/cm^3}$$

**Prob. 1.11**
*Label atom planes in Fig. 1.8b.*




**Prob. 1.12**
*Find atoms/cell and nearest neighbor distance for sc, bcc, and fcc lattices.*
(see solution to Prob. 1.5)

| | | |
|---|---|---|
| for sc | atoms/cell = | $\frac{1}{8}(8) = 1$ |
| | nearest neighbor = | a |
| for bcc | atoms/cell = | $\frac{1}{8} + 1 = 2$ |
| | nearest neighbor = | $\frac{a}{2}\sqrt{3}$ |
| for fcc | atoms/cell = | 4 |
| (see Example 1-1) | nearest neighbor = | $\frac{1}{2}a\sqrt{2}$ |



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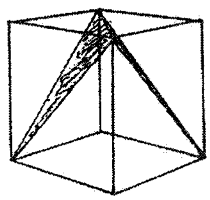
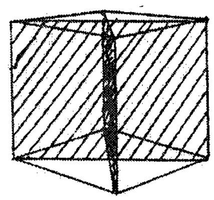
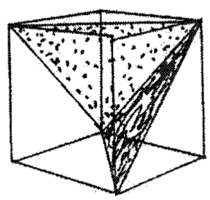
**Prob. 1.13**

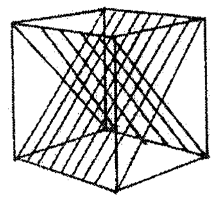
*Show four {111} planes. Repeat for {110} planes.*





{ 111 }   { 110 }







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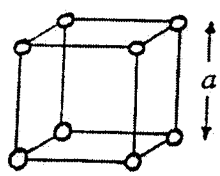
**Prob. 1.14**

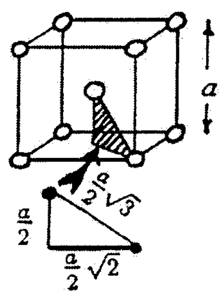
*Find fraction occupied in sc, bcc, diamond.*

sc



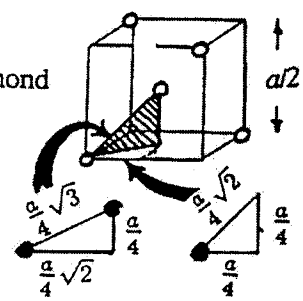

atoms/cell $= \frac{1}{8}(8) = 1$
nearest neighbor distance $= a$
maximum sphere radius $= a/2$
vol. of each sphere $= \frac{4}{3}\pi(\frac{a}{2})^3$
total occupied vol.
$= 1$ atom/cell$\times \frac{\pi}{6}a^3$
vol. of unit cell $= a^3$
fraction occupied $= \frac{\pi}{6} = \mathbf{0.52}$

bcc




2 atoms/cell
nearest neighbor distance $= \frac{a}{2}\sqrt{3}$
$r_{max} = \frac{a}{4}\sqrt{3}$
fraction occupied
$= (\frac{4}{3}\pi(\frac{a}{4}\sqrt{3})^3 \times 2)/a^3$
$= \frac{\pi}{8}\sqrt{3} = \mathbf{0.68}$

diamond




8 atoms/cell (4 from fcc +
4 at $\frac{1}{4}, \frac{1}{4}, \frac{1}{4}$ from fcc atoms)
nearest neighbor distance $= \frac{a}{4}\sqrt{3}$
$r_{max} = \frac{a}{8}\sqrt{3}$
fraction occupied
$= (\frac{4}{3}\pi(\frac{a\sqrt{3}}{8})^3 \times 8)/a^3$
$= \frac{\pi}{16}\sqrt{3} = \mathbf{0.34}$



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**Prob. 1.15**
*Find Ge and InP densities as in Example 1-3.*

The atomic weight of Ge is 72.6; for In, 114.8; for P, 31.

For Ge: $a = 5.66\text{Å}$, 8 atoms per cell

$$\frac{8}{a^3} = \frac{8}{(5.66\times10^{-8})^3} = 4.41\times10^{22}\ \text{atoms/cm}^3$$

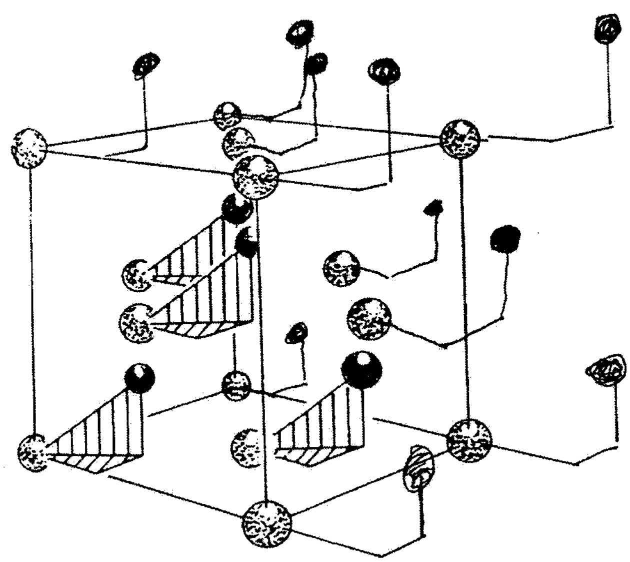
$$\text{density} = \frac{4.41\times10^{22}\times72.6}{6.02\times10^{23}} = \mathbf{5.32\ g/cm^{-3}}$$

For InP: $a = 5.87\text{Å}$, 4 In + 4 P per cell

$$\frac{4}{a^3} = \frac{4}{(5.87\times10^{-8})^3} = 1.98\times10^{22}\ \text{atoms/cm}^3$$

$$\text{density} = \frac{1.98\times10^{22}\times(114.8+31)}{6.02\times10^{23}} = \mathbf{4.79\ g/cm^{-3}}$$

**Prob. 1.16**
*Sketch diamond lattice and show only four atoms in the interpenetrating fcc are in the unit cell.*



**Prob. 1.17**

*What composition of AlSbAs is lattice matched to InP? InGaP to GaAs? What are the $E_g$'s?*

From Fig. 1-15 $AlSb_xAs_{1-x}$ ternary crosses the InP lattice constant at $x = 0.43$ where $E_g = 1.9$ eV

$In_xGa_{1-x}P$ crosses the GaAs lattice constant at $x = 0.48$, where $E_g = 2$ eV

**Prob. 1.18**

***What weight of As ($k_d = 0.3$) should be added to 1 kg Si to achieve $10^{15}cm^{-3}$ doping during initial Czochralski growth?***

**The atomic weight of As is 74.9.**
**$C_s = k_d C_L$, thus $C_L = 10^{15} / 0.3 = 3.33 \times 10^{15}$ cm$^{-3}$**
**Calculating the melt volume from the weight of Si only, and neglecting the difference in density for solid and molten Si,**

$$\frac{1000\text{ g of Si}}{2.33\text{ g/cm}^3} = 429.2\text{ cm}^3\text{ of Si}$$

$$3.33\times10^{15}\text{cm}^{-3}\times429.2\text{cm}^3 = 1.43\times10^{18}\text{ As atoms}$$

$$\frac{1.43\times10^{18}\times74.9}{6.02\times10^{23}} = 1.8\times10^{-4}\text{ g} = \mathbf{1.8\times10^{-7}}\text{ kg of As.}$$



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