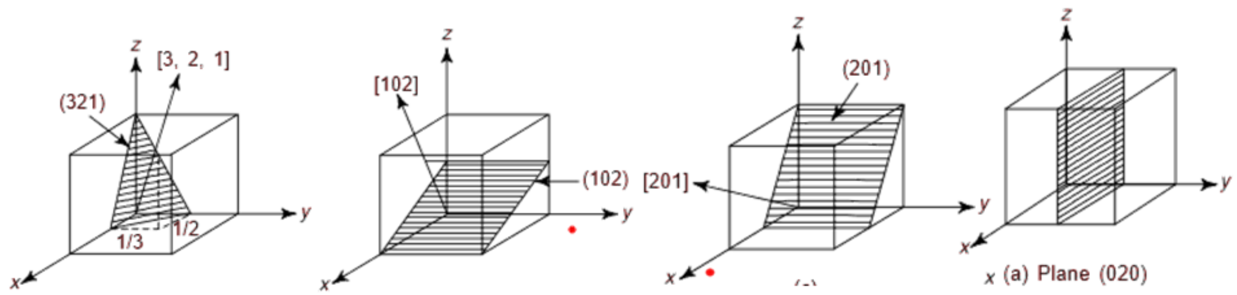
1a. Draw the planes and directions of FCC structures (321), (102), (201) and (020). (4M)



1b. Determine the packing efficiency and density of sodium chloride from the following data: (i) radius of the sodium ion = 1.02 Å, (ii) radius of chlorine ion = 1.61 Å (iii) atomic mass of sodium = 22.29 amu and atomic mass of chlorine = 31.05 amu. (**3 M**)

The unit cell structure of NaCl is FCC. We can see that the Na^+ and Cl^- ions touch along the cube edges.

Lattice parameter, a = 2 (radius of Na+ + radius of Cl–) = 2(1.02 + 1.61) = **5.26 Å**

Atomic Packing Fraction = Volume of ions present in the unit cell/ Volume of the unit cell

$$= \frac{4(4/3)\pi r_{Na^+}^3 + 4\left(\frac{4}{3}\right)\pi r_{Cl^-}^3}{a^3}$$

$$= \frac{16\pi}{3}\left[\frac{(1.02^3 + 1.61^3)}{5.26^3}\right]$$

=0.602 or 60.2% **(1.5 M)**

Density =Mass of the unit cell/Volume of the unit cell

=4(22.99+31.05)*1.66*10^-27/(5.26*10^-10)^3

=2465 kg/m^3 or 2.465 gm/cm^3 **(1.5 M)**

1c. Aluminium has FCC structure. Its density is 2100 kg/m3. Find the unit cell dimensions and atomic diameter. Given at. weight of Al = 23.98. (3 M)

$$\text{Density} = \frac{nm}{a^3} N_A$$

=2100 Kg/m^3 =2.1 gm/cm^3

$2.1 = \frac{4*23.98}{a^3*6.023*10^{23}}$ =>a=4.23x10^{-10} or 4.23 Å

For FCP structure, r=a/2*1.414=4.23/2*1.414=1.852988 Å

Diameter = 2r = 3.70 Å

2a. Calculate the planar atomic densities of planes (100), (110) and (111) in FCC unit cell and apply your result for lead (FCC form). (3 M)

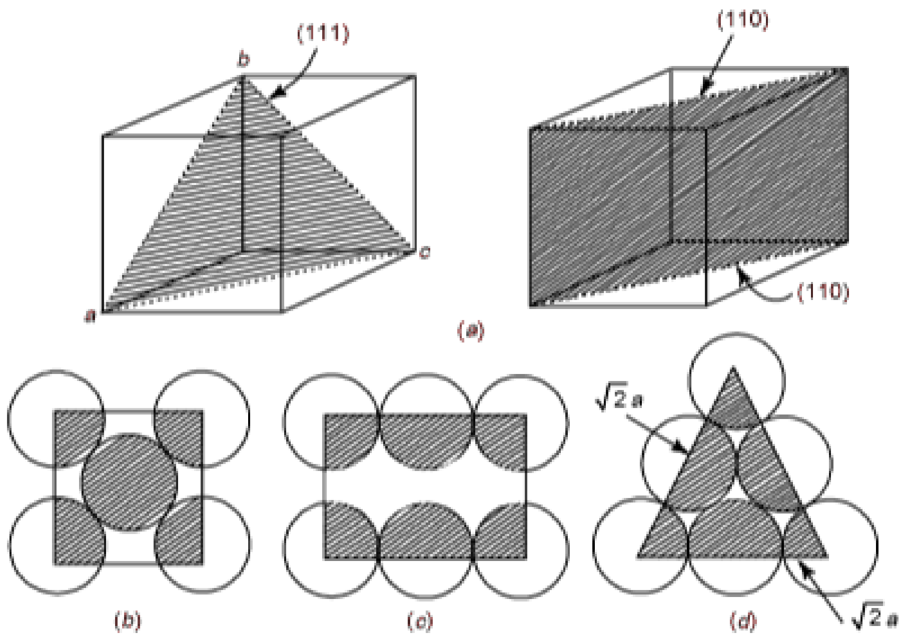


Fig. 3.44 Distribution of atoms in planes (100), (110) and (111) in FCC unit cell

Number of atoms contained in (100) plane is $4 \times \frac{1}{4} + 1 = 2$

Let a be the edge of the unit cell and r the radius of the atom, then

$$a = 2\sqrt{2}\ r$$

∴ Planar density of plane (100)

$$= \frac{2}{4 \times 2r^2} = \frac{0.25}{r^2}$$

The radius of lead atom is 1.75 Å. The planar density of (100) plane of lead

$$= \frac{0.25}{(1.75 \times 10^{-7})^2} = 8.2 \times 10^{12} \text{ atoms/mm}^2$$

$$= 8.2 \times 10^{18} \text{ atoms/m}^2$$

(ii) Plane (110): From Fig. 3.44(c), we have the number of atoms contained in plane (110)

$$= 4 \times \frac{1}{4} + 2 \times \frac{1}{2} = 2$$

The top edge of the plane (110) is $4r$, whereas the vertical edge $= a = 2\sqrt{2}\,r$. Thus the planar density of (110)

$$= \frac{2}{8\sqrt{2r^2}} = 0.177/r^2$$

In case of (110) plane in lead, we have planar density $= \dfrac{0.177}{(1.75\times10^{-2})^2}$

(iii) From Fig. 3.44(d), we have the number of atoms contained in the plane (111)

$$= 3 \times \frac{1}{6} + \frac{3}{2} = 2$$

Area of (111) plane $= \dfrac{1}{2}\sqrt{\dfrac{3}{2}}\,a\sqrt{2}\,a = 4\sqrt{3r^2}$

$\therefore$ Planar density of (111) $= \dfrac{2}{4\sqrt{3r^2}} = \dfrac{0.29}{r^2}$

For lead crystal, we obtain the value 9.5×10^{12} atoms/mm^2.

2b. The force of attraction between ions of Na and Cl is 2.02×10^{-9} N when the two ions just touch each other. Given: ionic radius of Na^+ ion is 1.1 Å, e = 1.6×10^{-19} C, $\varepsilon_o = 8.854\times10^{-12}$ $C^2/N - m^2$. Find the radius of Cl^- ion. (2 M)

$$\text{We have } F_1 = -\frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 r_2} \text{ (force of attraction)}$$

$r=3.37*10^{-9}$ m

$r = r_{Na}+r_{cl}$

$\mathbf{r_{cl-}}$=3.37-1.1 Å= **2.27 Å**

2c. The empty electron states are available immediately above the fermi level in a material. What type of material it is? And find the flux per unit potential gradient (5 M)

Ans: Conductor; Conduction by Free Electrons thoery

As conductivity σ is by definition the flux per unit potential gradient, we have

$$\sigma = \frac{ne^2\tau}{m}$$

3a. There are 10^9 electrons/m^3, which serves as carriers in a material. The conductivity of material is 0.01 Ohm^{-1}/m. Find the drift velocity of these carriers, when 0.17 Volt is applied across 0.27 mm distance with the material. Given: e = 1.602×10^{-19} C and m = 9.1×10^{-31} kg. (3M)

$$E=V/d$$

$$=630 \text{ V/m}$$

Let v be the drift velocity.

$$\text{The conductivity } \sigma = \frac{nev}{E}$$

$$0.01=2.54\text{x}10^{-13} * v$$

$$\mathbf{V=3.93x10^{10}\ m/s}$$

3b. Find the conductivity of copper at 300 K. The collision time for electron scattering in copper at 300 K is 4 x10^{-14} sec. Given that density of copper = 8960 kg/m^3, atomic weight of copper = 53.54 amu and mass of an electron = 9.1x10^{-31} kg. (3M)

$$\text{We know that the carrier concentration } = \frac{\text{Avogadro's number} \times \text{Density}}{\text{Atomic weight}}$$

$$n=6.023*10^{23} *8960/53.54$$

$$=1.0\text{x}10^{26}\ \text{m}^{-3}$$

$$\sigma = \frac{e^2nt}{m}$$

$$=(1.6\text{x}10^{-19})^2\ \text{x}10^{26}\text{x}4\ \text{x}10^{-14}/9.1\text{x}10^{-31}$$

$$\mathbf{=1.13x10^5\ ohm^{-1}m^{-1}\ or\ 1.13x10^5\ mho/m}$$

3c. If someone were to give you a poly crystalline material of $NaFePO_4$, how would you go about discovering the crystal structure, and what theory and principle would you use to do so? Explain your method with a neat sketch. (4M)

Ans: Powder crystal x-ray diffraction technique used to determine the structure of the material

4a. Calculate the resistance of a Cu wire 100 cm long and having cross-sectional area of 3 sq. mm at 20°C. Given, the resistivity of Al at 20°C = 2.66 x10^{-8} ohm-m (2M)

$$R = \frac{\rho l}{A}$$

$$=2.66\ \text{x}10^{-8}\text{x}1/3\text{x}10^{-6}$$

$$\mathbf{=8.87x10^{-3}\ ohm}$$

4b. The critical temperature of mercury is 5.2 K. Calculate the wavelength of a photon whose energy is just sufficient to break up Cooper pairs in mercury at T = 0. In what region of the electromagnetic spectrum are such photons found? (4M)

The Cooper pair binding energy, or gap energy, is $\mathbf{E_g=3kT_c}$

$$=3x1.4x10^{-23}x5.2$$

$$=2.184x10^{-22}\ \text{J} =1.36x10^{-3}\ \text{eV}$$

$$Eg = hv = hc/\lambda$$

$$\lambda =6.6x10^{-34}x3x10^{8}/2.18x10^{-22}$$

$$= 9x10^{-4}\ \text{m}$$

Obviously, these photons are in the very short wavelength part of the microwave region

4c. What are type-I and type-II superconducting materials? Give three examples of each why type-II materials are preferred for applications of superconductivity. (4M)

5a. Find the shortest wavelength of the x-rays emitted by an x ray tube operating at 30 KV (3M)

$$\frac{hc}{\lambda_{min}} = eV$$

$$\lambda_{min} = \frac{hc}{ev} = \frac{12375}{V} = \frac{12375}{30x10^3} = \mathbf{0.4125}\ \text{Å}$$

5b. A certain crystal has axial units x : y : z of 0.424:1:0.367. Find the Miller indices of crystal faces whose intercepts are 0.212:1:0.183.

h=x/a; k=y/b ; k=z/c

h=0.424/0.212=2 ; k=1/1=1; l=0.367/0.183

(2 1 2)

5c. What are polar and non-polar dielectrics? Derive Clausius-Mosotti equation for a solid dielectric exhibiting electronic polarizability. (4 M)

6a. Find the total polarizability of CO_2, if its susceptibility is 0.985×10^{-3} and density is 1.977 kg/ m^3 (4M)

Ans: $3.22x10^{-40}$

$$\chi = \frac{N_A \rho \alpha_e}{M \varepsilon_o}$$

Here χ=0.985 × 10^{-3}, N_A= 6.023x10^{26} , ρ=1.977 and M=Molecular weight CO2 is 44.01 g/mol

The total polarizability $\alpha_e = \frac{\chi M \varepsilon_o}{N_A \rho}$

=0.985 × 10^{-3}x44.01x8.85x10^{-12}/(6.023x10^{26}x1.977)

=3.22x10^{-40} F.m^2.

6b. A solid elemental dielectric having density of 3 × 10^{28} atoms/m^3 shows an electronic polariz ability of 10^{-40} F.m2. Assuming the internal electric field to be a Lorentz field, find the dielectric constant of the material. (4M)

Ans: 1.339

$$\varepsilon_r = \frac{\alpha_e N}{\varepsilon_0} + 1$$

$$= \frac{\mathbf{10^{-40} x 3 x 10^{28}}}{\mathbf{8.85 x 10^{-12}}} + \mathbf{1 = 1.339}$$

6c. With usual notations show that P = $\varepsilon_0(\varepsilon_r - 1)$ E (2M)

$$P = N\ \alpha_e \left[E + \frac{P}{3\varepsilon_0}\right]$$

We know that,

$$D = \varepsilon_0\ E + P$$

$$\frac{P}{E} = \frac{D}{E} - \varepsilon_0$$

From the definition of electric displacement vector,

$$D = \varepsilon\ E$$

Therefore,

$$\frac{P}{E} = \varepsilon - \varepsilon_0 = \varepsilon_r\ \varepsilon_0 - \varepsilon_0$$

where $\varepsilon_r = \varepsilon_r \varepsilon_0$

$$\frac{P}{E} = \varepsilon_0(\varepsilon_r - 1)$$

or, $P = E\ \varepsilon_0\ (\varepsilon_r - 1)$

7a. Write a short note on Dia, Para, Ferromagnetic materials and their applications (5M)

7b. The index of refraction for LiF is 1.395, its density is 2.635×10^3 kg/m3, and its molecular weight is 26×10^{-3} kg/mol. (5M)
Recall that $\varepsilon_0 = 8.854 \times 10^{-12}$ C/V-m.
***1*: Calculate the total polarizability for LiF.**
***2*: Calculate the electronic contribution to the total polarizability.**
Combine your information to calculate the ionic polarizability, α_i

Answers: $\alpha = [3(8.854 \times 10^{-12})(26 \times 10^{-3})/(6.02 \times 10^{23})(2.635 \times 10^3)][(9-1)/(9+2)] = 3.166 \times 10^{-40}$F-m^2; $\alpha_e = [3(8.854 \times 10^{-12})(26 \times 10^{-3})/2(6.02 \times 10^{23})(2.635 \times 10^3)][(1.95-1)/(1.95+2)] = 5.2 \times 10^{-41}$F-m^2.$\alpha_i = \alpha - \alpha_e = 3.16 \times 10^{-40} - 5.2 \times 10^{-41} = 2.64 \times 10{-}40$ F-m^2.

8a. A magnetic material has a magnetization of 3000 A/m and a flux density of 0.005 wb/m^2. Calculate the magnetic force and the relative permeability of the material (4M)
Ans: 977.72 A/m and 4.068

$$H = \frac{B}{\mu_0} - M = \frac{0.005}{12.57x10^{-7}} - 3000 = \mathbf{977.72}\, Am^{-1}$$

$$\mu = \frac{B}{\mu_0 H} = 0.\frac{005}{12.57x10^{-7}x\mathbf{977.72}} = \mathbf{4.068}$$

8b. Assume that iron atoms have magnetic moment of two Bohr magnetons. Calculate the Curie constant if its density is 7150 kg/m^3 and atomic weight is 55.8 (4M)

Ans: 0.00241

$$C = N\beta^2\mu_0/k$$

$$C = \frac{6.022x10^{23}x7150x(2x9.27x10^{-24})^2x4x3.1415x10^{-7}}{55.8x1.38x10^{-23}}$$

=0.00241or $2.41x10^{-3}$

8c. If a material have $\varepsilon < 0$, $\mu < 0$, What will happen electromagnetic radiation fall on surface? Why? (2M)

Ans: If a material have $\varepsilon < 0$, $\mu < 0$, resultant refractive index is NAGATIVE, So that electromagnetic radiation completely observed by the material and usually found phenomena in meta materials.

9a. Critical temperature of a superconductor at zero magnetic field is T_C. Determine the temperature at which the critical field becomes half of its value at 0K (4M)

Ans: 0.707 Tc

Super conductor critical field $H_c=H_0[1-(T/T_c)^2]$ =>$1/2=1-(T/T_c)^2$=>$T_{1/2}=\sqrt{T_c^2/2}$=> $\mathbf{T_{1/2}=0.707T_c}$

9b. For a certain metal the critical magnetic field is 4 × 10^3 A/m at 6K and 2 × 10^4 A/m at 0K. Determine its transition temperature (4M)

$$T_C = \frac{T}{\left[1 - \left(\frac{H_C(T)}{H_c(0)}\right)\right]^{1/2}}$$

$$T_C = \frac{6}{\left[1 - \left(\frac{4x10^3}{2x10^4}\right)\right]^{1/2}} = \mathbf{6.7\ K}$$

10a. Explain Size effects in nano materials (4M)

10b. How to characterize nano materials? Explain any one method with neat sketch (4M)

Ans: SEM, TEM, AFM

10c. A material has completely filled electronic states and possess a small value of induced magnetic moment, when there is an applied magnetic field. What type materials they are? Find the susceptibility of that material? (4M)

Langevin' s Theory of Diamagnetism

Diamagnetic material has completely filled electronic states and possess a small value of induced magnetic moment.

$$\chi = -\frac{Ne^2 \mu_0 \mu_r r_o^2}{6m}$$