B.Sc. (Electronics) Examination 2013
(First Semester)
Basic. Electronics – I
Paper : second
Code : AS – 2788

SECTION-A

Q.1 (i) (c)
(ii) (d)
(iii) (c)
(iv) (c)
(v) (c)
(vi) (a)
(vii) (d)
(viii) (d)
(ix) (a)
(x) (b)

SECTION- B

Q.2 (i) Electrical conductivity of Intrinsic Semiconductor

If a semiconductor is placed in an external electric field, its charge carriers experience a force and move in direction of field. This is known as drift. Let ρ be the density of free charges in conductor, v is average drift velocity.

Consider a cylindrical shape. Let length equal to v for unit time and cross-section is unity, then charge contained in cylinder is ρv. The current through the unit cross-section i.e. current density J will be

$$J = \rho v \quad \text{—— (1)}$$

If semiconductor is placed in external field, E then electron and holes acquire average drift velocities v_e & v_h respectively. Therefore,

$$J_{drift} = e(n v_e + p v_h) \quad \text{—— (2)}$$

where n, & p are concentrations of electrons & holes respectively.

since $\mu_e = \frac{v_e}{E}$ and $\mu_h = \frac{v_h}{E}$ = mobility

then $J_{drift} = eE(n\mu_e + p\mu_h)$ —— (3)

since $J = \sigma E$ —— (4)

From eq^n (3) & (4), we get

$$\boxed{\sigma = e(n\mu_e + p\mu_h)}$$

Q.1 (ii)

The expression for electrical conductivity is

$$\sigma = e(n\mu_n + p\mu_p) = n_i e(\mu_n + \mu_p)$$

for intrinsic semi-conductor, $n = p = n_i$

and given $n_i = 2.5 \times 10^{13} /cm^3$

$$\mu_e = 3600 \ cm^2/Vs$$

$$\mu_h = 1800 \ cm^2/Vs$$

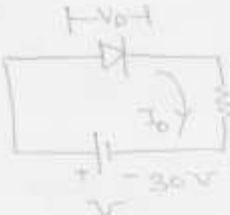
therefore, $\sigma = 1.6 \times 10^{-19} \times 2.5 \times 10^{13} \times (1800 + 3600)$

$$= 1.6 \times 2.5 \times 5.4 \times 10^{-19+13+3}$$

$$= 21.6 \times 10^{-3}$$

$$= 0.0216 \ /\Omega\text{-cm}$$

Q.3.



The voltage across diode

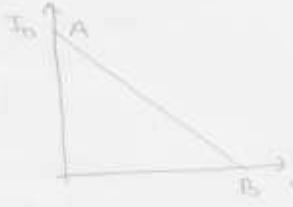
$$V_D = V - I_D R_L \quad \text{—— (1)}$$

and V and R_L are fixed values

when $I_D = 0$ then $V = V_D$

when $V_D = 0$ then $I_D = \frac{V}{R_L}$

we get DC load line.



for $I_D = 0$; $V = V_D = 30 \ V$

so Point B will be (30, 0)

for $V_D = 0$; $I_D = \frac{V}{R_L} = \frac{30V}{3k\Omega} = 10 \ mA$

so Point A will be (0, 10)

since slope of line $= -\frac{1}{R_L} = -\frac{1}{3k\Omega} = -3.33 \times 10^{-3}$ mho

and slope is negative.

Q. 4 Fermi level of N-type semi-conductor

Donor atoms represent isolated energy levels close to conduction band and little energy is required to push an electron from donor level into conduction band where it will be available for electrical conductivity.

Energy Band Diagram

N_D = Density of donor atoms
E_i = Energy of donor level

At low temperatures, let assume
$(E_c - E_F) > 4k_BT$

Since the density of electron in conduction band

$$n_e = 2\left(\frac{2\pi m_e^* k_BT}{h^2}\right)^{3/2} \exp\left(\frac{E_F - E_c}{\cancel{2}k_BT}\right) \quad \text{--- (1)}$$

if assume that E_F lies more than a few k_BT above donor level then density of donor in E_i level which give electrons to CB is

$$N_D\left[1 - F(E_i)\right] \propto N_D \exp\left(\frac{E_i - E_F}{k_BT}\right) \quad \text{--- (2)}$$

Since Density of empty donors = density of e^- in CB then from eq^n (1) & (2) ;

$$2\left(\frac{2\pi m_e^* k_BT}{h^2}\right)^{3/2} \exp\left(\frac{E_F - E_c}{k_BT}\right) = N_D \exp\left(\frac{E_i - E_F}{k_BT}\right)$$

or, $$\frac{\exp\left(\frac{E_F - E_c}{k_BT}\right)}{\exp\left(\frac{E_i - E_F}{k_BT}\right)} = \frac{N_D}{A} \; ; \quad \text{where } A = 2\left(\frac{2\pi m_e^* k_BT}{h^2}\right)^{3/2}$$

Taking $\log_e$ on both side

$$\frac{(E_F-E_c)}{k_BT} - \frac{(E_i-E_F)}{k_BT} = \log_e\left(\frac{N_D}{A}\right)$$

or, $$\frac{2E_F-(E_i+E_c)}{k_BT} = \log_e\left(\frac{N_D}{A}\right)$$

or, $$E_F = \frac{(E_i+E_c)}{2} + \frac{k_BT}{2}\log_e\left(\frac{N_D}{A}\right)$$

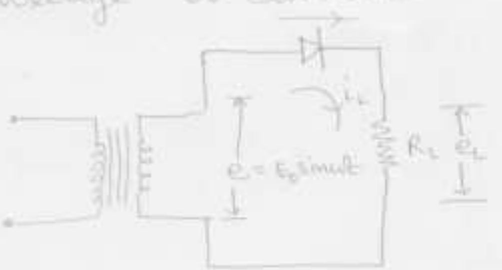
at $T = 0^\circ K$;

$$E_F = \frac{E_i+E_c}{2}$$

Fermi level lies between lowest of conduction band and donor energy level.

Q.5 <u>Half-wave rectifier</u>

Rectifier is a device, converts alternating voltage or current into unidirectional voltage or current.



Alternating voltage $e = E_0 \sin\omega t$ is applied across the series combination of the diode and a resistance R_L, load resistance.

Diode becomes forward biased for $0 \le t \le T/2$ and becomes reverse biased for $T/2 \le t \le T$. Then circuit current i_L becomes

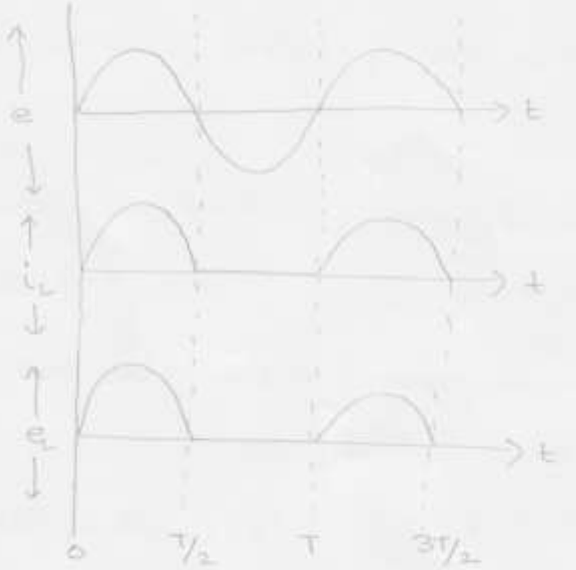
$$i_L = \frac{e}{r_f + R_L} \quad \text{for } 0 \le t \le T/2$$

$$= \frac{e}{r_b + R_L} = 0 \quad \text{for } T/2 \le t \le T \qquad \text{since } r_b \approx \infty$$

then voltage across load 'e_L' will be

$$e_L = \frac{E_0 \sin\omega t}{(1 + r_f/R_L)} \; ; \text{ for } 0 \le t \le T/2$$

$$= 0 \qquad ; \text{ for } T/2 \le t \le T$$



waveform of e, i_L and e_L

the magnitude varies with time, they consists alternating part e_{Lac} superimposed over direct part e_{Ldc}, hence

$$e_L = e_{Ldc} + e_{Lac} \qquad \text{—— (1)}$$

Integrating over time period T,

$$\int_0^T e_L\,dt = \int_0^T e_{Ldc}\,dt + \int_0^T e_{Lac}\,dt \quad \text{——— (2)}$$

since $\int_0^T e_{Lac}\,dt = 0$

therefore
$$e_{Ldc} = \frac{1}{T}\int_0^T e_L\,dt \quad \text{——— (3)}$$

Now
$$e_{Ldc} = \frac{1}{T}\left[\int_0^{T/2} \frac{E_0 \sin\omega t}{(1+r_f/R_L)}\,dt + \int_{T/2}^{T} 0\,dt\right]$$

$$= \frac{E_0}{\pi(1+r_f/R_L)}$$

If $r_f \ll R_L$ then
$$e_{Ldc} = \frac{E_0}{\pi} \quad \text{—— (4)}$$

Now, alternating part of output voltage (e_{Lac}),

$$e_{Lac} = e_L - e_{Ldc}$$

$$= \frac{E_0}{(1+r_f/R_L)}\left(\sin\omega t - \frac{1}{\pi}\right) \quad \text{for } 0 \le t \le T/2$$

$$= -\frac{E_0}{\pi(1+r_f/R_L)} \quad \text{for } T/2 \le t \le T$$

Hence, mean square value over one period is

$$e_{Lac,ms} = \frac{1}{T}\int_0^T e_{Lac}^2\,dt$$

$$= \frac{1}{T}\left[\frac{E_0^2}{(1+r_f/R_L)^2}\left\{\int_0^{T/2}\left(\sin\omega t - \frac{1}{\pi}\right)^2 dt + \int_{T/2}^{T}\left(-\frac{1}{\pi}\right)^2 dt\right\}\right]$$

$$= \frac{E_0^2}{(1+r_f/R_L)^2}\,\frac{\pi^2-4}{4\pi^2} \quad \text{——— (5)}$$

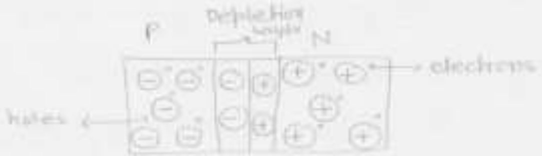
ripple factor
$$= \gamma = \frac{e_{Lac,rms}}{e_{Ldc}}$$

$$= \frac{E_0}{2\pi(1+r_f/R_L)}\sqrt{\pi^2-4} \times \frac{\pi(1+r_f/R_L)}{E_0}$$

$$= \sqrt{\frac{\pi^2-4}{4}}$$

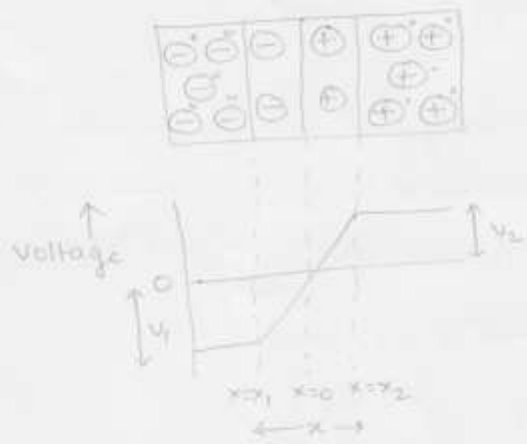
$$= 1.21$$

Q.6. **Depletion layer**



when electron crosses from N to P side, it combines with hole present at P side. Similarly the hole crosses from P to N and combines with electron. Close to junction, nearly all the mobile free charges diffuse to other side and leaves a narrow region at junction having no mobile charge carries. It is known as depletion region.

width of Depletion layer



width of depletion region
$x = x_1 + x_2$

and

Potential barrier

$V_B = |V_1| + |V_2|$

By Poisson's eqn: $\frac{d^2V}{dx^2} = -\rho/\epsilon$ where $\rho = -eN_a$

then $$\frac{d^2V}{dx^2} = \frac{eN_a}{\epsilon} \quad \text{—— (1)}$$

Integrating we get $\frac{dV}{dx} = \frac{eN_a}{\epsilon}x + C_1$

at $x = -x_1$, $\frac{dV}{dx} = 0$ then $C_1 = \frac{eN_a x_1}{\epsilon}$

& $$\frac{dV}{dx} = \frac{eN_a x}{\epsilon} + \frac{eN_a x_1}{\epsilon} \quad \text{—— (2)}$$

Integrating it again, we get

$$V = \frac{eN_a x^2}{2\varepsilon} + \frac{eN_a x_1 x}{\varepsilon} + c_2 \quad \text{—— (3)}$$

applying the boundary condition

$$x = 0 \;;\; V = 0 \;\Rightarrow\; c_2 = 0$$

$$V = \frac{eN_a x^2}{2\varepsilon} + \frac{eN_a x_1 x}{\varepsilon}$$

at $x = -x_1$, $V = V_1$ $\Rightarrow$ $\boxed{V_1 = -\frac{eN_a x_1^2}{2\varepsilon}}$ —— (4)

Similarly for potential distribution in space charge region on n side,

$\frac{d^2V}{dx^2} = -\frac{eN_d}{\varepsilon}$ and solving the equation gives

$$\boxed{V_2 = \frac{eN_d x_2^2}{2\varepsilon}} \quad \text{—— (5)}$$

since crystal in electrically neutral then

$$N_a x_1 = N_d x_2 \quad \text{—— (6)}$$

and $V_B = |V_1| + |V_2| = e\left(\frac{N_a x_1^2 + N_d x_2^2}{2\varepsilon}\right)$ —— (7)

from eq^n (6) and (7)

$$x_1 = \left(\frac{2\varepsilon V_B}{eN_a\left(1+\frac{N_a}{N_d}\right)}\right)^{1/2}$$

and $x_2 = \left(\frac{2\varepsilon V_B}{eN_d\left(1+\frac{N_d}{N_a}\right)}\right)^{1/2}$

Barrier width $x = x_1 + x_2$

$$\boxed{x = \left[\frac{2\varepsilon V_B}{e(N_a+N_D)}\right]^{1/2}\left[\left(\frac{N_d}{N_a}\right)^{1/2} + \left(\frac{N_a}{N_d}\right)^{1/2}\right]}$$

8.7. Law of mass-action

The density of electrons in conduction band

$$n_e = 2\left(\frac{2\pi k_B T}{h^2}\right)^{3/2} (m_e^* m_h^*)^{3/4} \exp\left(-E_g/2k_BT\right) \quad —(1)$$

and density of holes in valence band is

$$n_h = 2\left(\frac{2\pi k_B T}{h^2}\right)^{3/2} (m_e^* m_h^*)^{3/4} \exp\left(-E_g/2k_BT\right) \quad —(2)$$

At a given temperature, n_e and n_h both are equal and independent of Fermi energy level. therefore $n_e = n_h = n_i$ = intrinsic density

Let $n_e \times n_h$

$$= 4\left(\frac{2\pi k_B T}{h^2}\right)^{3} (m_e^* m_h^*)^{3/2} \exp\left(-E_g/k_BT\right) \quad —(3)$$

$= n_i^2$

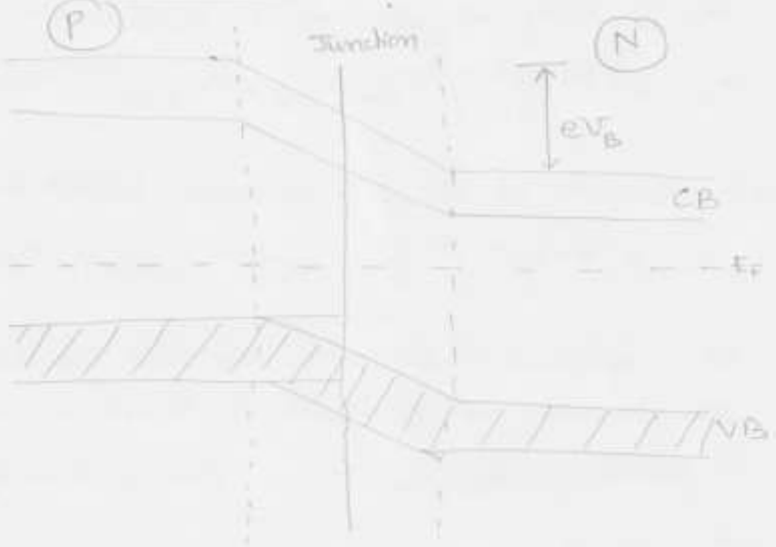
It given that product of hols and electron densities at a given temperature is a constant since each term on right hand of eq^n(3) is constant at a given temperature.

Let impurity is added to increase density of electrons (N-type), then there will be corresponding decrease in p, so that product np remains constant. Similarly the case of P-type, it will remain constant.

In intrinsic, $np = n_i^2$

"The product np remains constant for a semi-conductor irrespective of extrinsic or intrinsic."

Q.8. (i) shift of energy band edge at PN junction ~~at~~ in a diode :-



Electrons from N crosses barrier and reach P side similarly holes cross barrier for N side. An internal potential barrier V_B exist between n and p regions. The band edges shifts themselves to make alignment of Fermi level. The conduction band of P-side shifted upward by eV_B over the conduction band of n-type where V_B is potential barrier. The CB of P-side at higher energy than conduction band of N-side. The electrons crossing the junction from P-region will not encounter barrier whereas electrons crossing from N-region will face barrier.

Q8. (ii) Einstein relation

Carrier transport mechanisms 'drift' and 'diffusion' are considered independent but they both depend on scattering processes. Einstein showed that the parameters describing the two processes, mobility μ and diffusion coefficient D are directly related. Under equilibrium condition, the drift and diffusion currents due to an excess density of electrons, then

$$(\delta n) e E \mu_n = e D_n \frac{\partial(\delta n)}{\partial x} \quad \text{—— (1)}$$

Now force on excess carriers

$$F = (\delta n) e E = \left[\frac{e D_n}{\mu_n}\right] \frac{\partial(\delta n)}{\partial x} \quad \text{—— (2)}$$

By making an analogy, between excess carriers in a semiconductor and gas molecules in low pressure gas, the force corresponding to the pressure gradient is equal to $(k_BT)\frac{\partial}{\partial x}(\delta n)$ —— (3)

then Comparing forces from (2) & (3), we get

$$k_BT = \frac{e D_n}{\mu_n}$$

$$D_n = \frac{\mu_n k_BT}{e}$$

So $\boxed{\frac{D_n}{\mu_n} = \frac{k_BT}{e}}$ similarly $\boxed{\frac{D_p}{\mu_p} = \frac{k_BT}{e}}$

Q.3. (iii) Wave-shaping circuits

The circuits which control the shape of the voltage and current waveforms are called wave-shaping circuits. They are clippers and clampers. The output of clipping circuit appears as if a portion of input signal were clipped off. Clamper circuit simply clamps the input signal to a different DC level.

Clippers :- clipping circuit requires a minimum of two components i.e. a diode and a resistor. DC battery also fix the clipping level. Input waveform can be clipped at different levels by simply changing battery voltage.

we get two types of clipper ; positive & negative clipper

Clampers :-

clamping is process of introducing a DC level into an ac signal.