Date .....

Photo - Tute - 1 - Max

① General Things :

(i) Plank's const = $h = 6.62 \times 10^{-34}$ kg m^2 / sec

(ii) 1 eV = 1.6×10^{-19} J

(iii) 1 W = 1 J / sec

(iv) 1 Whr = 1 W is consumed in 1 hour

(v) $\boxed{\text{Pay back} = \frac{\text{Demanded Power / Energy}}{\text{Produced Power / Energy}}}$

(vi) Insolation = Energy received from sunlight

(vii) $\boxed{E_{radiated} = \sigma A T^4}$

(i) $\sigma = 5.67 \times 10^{-8}$

(ii) Area

(iii) T in K

(viii) $\boxed{E \text{ at Earth atmos} = \frac{E_{rad}}{4\pi (R_{se})^2}}$ → energy

(vi) PV = photovoltaic = material thru which we extract

② How to solve :

(i) Find total energy produced w/ efficiency

(ii) Find required energy by using W or something

(iii) Convert things into correct unit J, sec, W

③ Si = 1.12 eV
Ge = 0.7 eV
GaAs = 1.47 eV
CdTe = 1.66 eV

⇒ Band Gap

④ $E = h\nu = \frac{hc}{\lambda}$

(i) to convert "h" into eV, just divide by "1.6×10^{-19}"

Photo - tute - 2 - hax

① $\boxed{n_o \times p_o = n_i^2}$

if pentavalent ⇒ n-type = majority = given conc.
" tri " ⇒ p- " = majority = given conc.

② $\boxed{\text{Conductivity} = \sigma = q\left[\mu_n n + \mu_p p\right]}$ unit Ωm

$\boxed{\text{Resistivity} = \rho = \frac{1}{\sigma}}$ unit = Ωm

where: μ_n = mobility of e^- unit $cm^2/V\,sec$
μ_p = " " holes
$n = p$ = conc. of e^- & holes doping
↳ unit atoms/cm^3

③ Current Density = $\boxed{J = q D_n \frac{dn}{dx}}$ unit A/cm^2

where: (i) D = diffusion coefficient
$= \frac{KT}{q}\mu_n = 0.026\mu_n$

(ii) $\frac{dn}{dx}$ = $\frac{\text{diff of conc. b/w 2 points}}{\text{given distance}}$

④ Recombination Rate:

$\boxed{RR = \frac{\Delta n}{\tau} = \frac{\Delta p}{\tau}}$

τ → Life-time of semiconductor time

④ $\boxed{\text{Absorbtion depth} = L = \frac{1}{\alpha}}$ unit = cm

where: α = absorbtion coefficient unit cm^{-1}

⑤ Diffusion Length = $\boxed{L_D = \sqrt{D\tau}}$ unit cm, m

where: τ = e^- lifetime
$D = \mu \frac{KT}{q}$

⑥ Recombination rate = $\boxed{R = \frac{\Delta n}{\tau}}$ unit atoms/sec

⑦ $\boxed{I_x = I_0 \exp\left[-\alpha x\right]}$ unit W

Absorbed = $I_x - I_0$

where: I_0 = incident power
α = absorbtion coff.
x = distance

Spiral

Tute-3-Max

(1) Built-in bias V ⇒ $V_{oi} = \frac{KT}{q} \ln\left(\frac{N_D N_A}{n_i^2}\right)$

(2) $V_{oc} = \frac{KT}{q} \ln\left(\frac{I_{sc}}{I_0} + 1\right)$

(3) $I_0 = q\, n_i^2 \left[\frac{D_n}{L_n n_0} + \frac{D_p}{L_p n_p}\right]$

$D = \frac{KT}{q} u$

(4) $I_{sc} = q A \phi$

$\phi = \frac{\text{Power Density}}{h\nu}$

only consider ϕ when things are being absorbed, if more than 1 is by a, consider ϕ_{total}

(5) $\eta = \frac{V_{oc} I_{sc} FF}{P_{in}}$ = Efficiency

(6) $I = I_{sc} - I_0 \left[\exp\left(\frac{qV}{KT}\right) - 1\right]$

Spiral

POSSESSION OF MOBILES IN EXAM IS UFM PRACTICE

Name: Anunay Dwivedi

Enrollment No: 19922102048

Jaypee Institute of Information Technology, Noida
T1 Examination, Even Semester 2025
B. Tech. VI Semester

Course Title: Photovoltaic Techniques
Course Code: 16B1NPH633

Maximum Time: 1 Hr
Maximum Marks: 20

After completion of the course, student should be able to

CO1:	Identify global energy issues, compare energy sources and explain semiconductor principles for solar cells
CO2:	Design and optimize solar cells by applying semiconductors principles to improve parameters like I-V characteristics, efficiency, I_{sc}, V_{oc} and FF
CO3:	Distinguish and analyze various solar cell technologies and photovoltaic systems including BOS components.
CO4:	Evaluate the design, size and cost of photovoltaic systems for recommending optimal solutions

Note: Attempt all questions.

Q. 1 (i) Mention the category of following energy sources:
(a) Petroleum oil (b) Hydro power (c) Solar energy

(ii) Define Albedo of earth. If its value is increased to 40%, then calculate the value of AM1.5G

(iii) With the help of I-V equation of a solar cell, find out the value of I_{sc} and V_{oc}.

(iv) In photovoltaic conversion, the potential energy of light generated election is increased and charge reaction takes place. True or False? Justify your answer.

[CO1 (Understanding), 1.5x4 = 6 Marks]

Q. 2 (i) Describe direct and indirect band gap semiconductor materials. Also discuss their advantage/disadvantage and applications in short.

(ii) With the help of band diagram, explain the working of a P-N junction diode under solar illumination.

(iii) Show that the maximizing the power output of a solar cell, leads to the expression:

$$V_{mp} = \frac{KT}{q}\left[\left(1+\frac{J_{sc}}{J_0}\right)\left(e^{-\frac{qV_{mp}}{KT}}-1\right)\right]$$

[CO2 (Applying), 2+3+3 = 8 Marks]

Q. 3 (i) A semiconductor material having band gap of 2 eV, is doped with 10^{16} P atoms/cm^3. Calculate the resistivity of the doped sample and also draw the energy band diagram showing the difference between E_i, E_f, E_v and E_c. Given parameters: $n_i = 1.5\times10^{10}$/cm^3, $\mu_e = 1500$ cm^2/V-s, $\mu_h = 500$ cm^2/V-s, KT/q = 0.0256 V

(ii) Two solar cells of band gap 1.2 eV and 1.7 eV, having front surface area of 100 cm^2 each are exposed by bi-chromatic light of wavelength 800 nm and 1000 nm respectively. The power density of both wavelength beams is 400 w/m^2 and 800 w/m^2 respectively. If $I_0 = 10^{-10}$ A/cm^2 then calculate the Isc and Voc of each cell at 300^{0}K.

[CO3 (Analyzing), 3+3 = 6 Marks]

****

Date .....

		Worst	What You Want	Expected	
	VLSI	B	B+	B+	B
α	Tele	B	B+	B	B
	Photo	B	B	B	B
	Lit	B	B	B	B
	ML	B+	B+	B+	B
o)	DMD	B+	B+	B+	B
	VL Lab	B	A	B+	A
	Tele Lab	B+	A	A	B
	Minor	B	B+	B	B
ln (500)					101

Worst : 28+63+98+7+8+14 = 168 = 7.3

WWW : 32+72+42+9+9+16 = 180 = 7.8

Exp : 32+48+63+8+9+14 = 174 = 7.5

b - CG-Analysis

Tute - Max

① Ideal Diode Eq^n:

$$\boxed{I = I_{sc} - I_0\left[\exp\left(\frac{qV}{KT}\right) - 1\right]}$$

where: I = current in solar cell
I_{sc} = Short Circuit curr
I_0 = Reverse saturation
K = Boltzman const.

(i) At open circuit ($I = 0$):

$$\boxed{I_0 = \frac{I_{sc}}{\exp\frac{qV_{oc}}{KT} - 1}}$$

$\therefore$ hence $\boxed{V_{oc} = \frac{KT}{q}\ln\left[\frac{I_{sc}}{I_0} + 1\right]}$

↳ $\frac{I_{sc}}{I_0} >>> 1 \Rightarrow$ and can be ignored OR not IDK

(ii) In parallel:

$$\boxed{J_{sc} = J_{sc1} + J_{sc2}}$$

$$\boxed{V_{oc} = \frac{KT}{q}\ln\left[\frac{I_{sc1} + I_{sc2}}{I_{01} + I_{02}} + 1\right]}$$

(iii) In series:

$$\boxed{J_{sc} = \min(J_{sc1}, J_{sc2})}$$

$$\boxed{V_{oc} = V_{oc1} + V_{oc2}}$$

② Peak Power $\Rightarrow$ $\boxed{P_{max} = V_{oc} I_{sc} FF}$ unit W

③ Efficiency $\Rightarrow$ $\boxed{\eta = \frac{P_{max}}{\text{Incident Power}} = \frac{P_{max}}{\text{area} \times \text{illumination}}}$

↳ W/m²

P_{in} = Power Density (W/m²)

std. illumination = AM 1.5G = 1000 W/m²

④ Fill Factor $\Rightarrow$ $\boxed{FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}}}$

V_{mp} = Volt at max Power Point
I_{mp} = Curr " " " "

Spiral

(5) Incident photon flux density = $b_o(E)$, R = Surface Reflectivity

x_n = ~~base~~ emitter thickness , x_p = base thickness , α = absorbtion coeff

(i) at Emitter = $(1-R)\, b_o(E)$

(ii) after Emitter = $b_o(E)\,(1-R)\exp(-\alpha x_n)$

(iii) at base = $b_o(E)\,(1-R)\exp(-\alpha x_n)\left(1-\exp(-\alpha x_p)\right)$ ⇒ being absorbed

→ photon flux density reaching the base

(6) Photocurrent Density = $\boxed{q \times \text{flux absorbed at base} = J_{ph}}$

(7) Quantum Efficiency ⇒ QE = $\dfrac{\text{collected carriers}}{\text{incident photons}}$

$$\boxed{QE = \frac{J_{ph}}{q\, b_o(E)} = (1-R)\exp(-\alpha x_n)\left(1-\exp(-\alpha x_p)\right)}$$

Tute-6-Hax

① $\boxed{\text{Efficiency} = \eta = \frac{V_{oc} I_{sc} FF}{P_{in}}}$

② $\boxed{V_{oc} = \frac{KT}{q} \ln\left(\frac{I_{sc}}{I_0} + 1\right)}$

③* $\boxed{V_{oc}' = V_{oc} + \frac{KT}{q} \ln(\text{no. of suns or change in intensity})}$

④ $\boxed{V_{oc}' = V_{oc} - 2.2\,mV\,(\text{change in tempt } °C)}$

⑤ $\boxed{\text{Refractive Index} = n_f = \sqrt{n_{Si}\, n_{\text{surrounding material}}}}$

⑥ $\boxed{\text{Thickness} = t = \frac{\lambda}{4 n_f}}$ (λ = wavelength)

⑦* $\boxed{I_{sc} \propto \text{light intensity}}$

⑧ $qV = E_g \Rightarrow \boxed{V_{oc} \leq \frac{E_g}{q}} \rightarrow$ Band Gap

⑨ η remains const. if intensity ↑ or ↓

↳ although slightly increases if intensity ↑ & decrease " " ↓

⑩ Red photon

↳ (1) Lower energy → goes deeper

→ where recombination happens

Blue photon

↳ (1) High energy → gets absorbed near surface hence high QE

⑪ AM1.5G = 1000 W/m²

$K = 1.38 \times 10^{-23}\ m^2 kg / s^2 K$

power point.

⚡ Combined Effect of Irradiance and Temperature on Solar Cell Performance

Parameter	Effect of Irradiance	Effect of Temperature
Short-Circuit Current (Isc)	Increases linearly with irradiance.	Slight increase with temperature.
Open-Circuit Voltage (Voc)	Slight increase with irradiance.	Decreases significantly with temperature.
Power Output (Pmax)	Increases with irradiance.	Decreases with temperature.
Efficiency	Increases with higher irradiance.	Decreases with higher temperature.
Fill Factor (FF)	Slight increase with irradiance.	Decreases slightly with temperature.

✅ Key Takeaways:

Ask anything
Reason
ChatGPT can make mistakes. Check important info.

💡 Key Takeaways:

1. **Photon Energy vs. Wavelength:**
   - Shorter wavelengths → Higher energy → Higher QE but surface losses.
   - Medium wavelengths → Ideal for maximum efficiency.
   - Longer wavelengths → Lower energy → Inefficient photon absorption.
2. **Solar Cell Efficiency:**
   - **Visible light** → Best efficiency.
   - **Blue/UV** → Surface losses reduce efficiency.
   - **IR/Red** → Low energy, less efficient.
3. **Optimal Material Choice:**
   - Solar cells are designed to match the solar spectrum for maximum efficiency.
   - **Silicon** is best suited for the **visible range**.
   - **Multi-junction cells** → Absorb a broader spectrum, boosting efficiency.

Ask anything
Reason
ChatGPT can make mistakes. Check important info.

🔥 Key Takeaways:

Loss Type	Cause	Effect	Optimization Strategies
Shading Loss	Grid fingers, busbars, external shading	Reduces current and causes hot spots	Thinner fingers, bypass diodes
Reflection Loss	High refractive index of silicon	Reduces incoming photon absorption	ARC coating, surface texturing
Transmission Loss	Photons with $E < E_g$ pass through	Reduces current output	Thicker active layer, reflectors
Recombination Loss	Electron-hole recombination	Reduces V_{oc}, FF, efficiency	Passivation, low-defect materials
Ohmic Loss (Series)	Current flow resistance	Lowers FF, causes voltage drop	Low-resistance contacts, LFC
Ohmic Loss (Shunt)	Leakage due to defects	Reduces V_{oc}, leakage current	Defect-free manufacturing

✅ Overall Optimization Strategy:

- **Reduce reflection and shading losses** → ARC coating, thinner fingers.
- **Minimize recombination** → Surface pa vation, low-defect materials.

Ask anything
Reason
ChatGPT can make mistakes. Check important info.

POSSESION OF MOBILES IN EXAM IS UFM PRACTICE.

Name Anurag Dwivedi

Enrollment No. 9922102042

Jaypee Institute of Information Technology, Noida
T2 Examination, EVEN 2025
B.Tech. 6th Semester

Course Title: Photovoltaic Techniques
Course Code: 16B1NPH633

Maximum Time: 1 Hr.
Maximum Marks: 20

After completion of the course, students should be able to

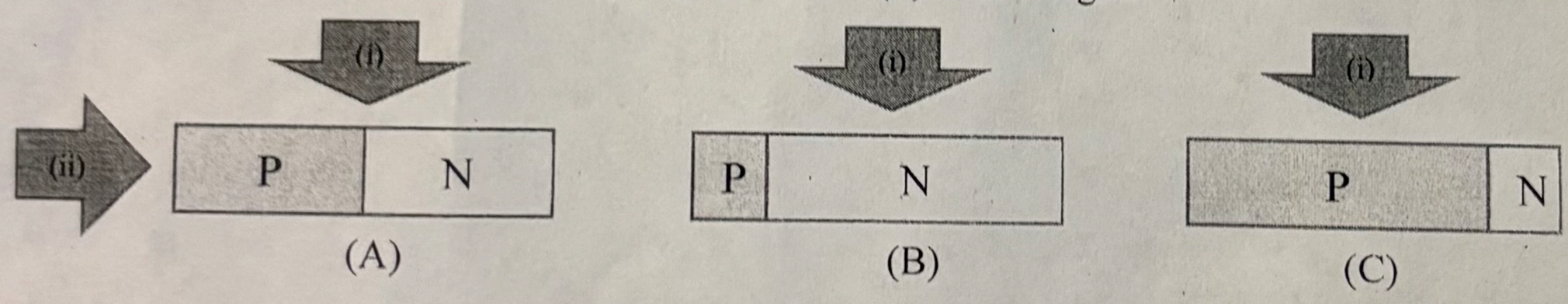
CO1:	Identify global issues, compare energy sources and explain semiconductor principles for solar cells.
CO2:	Design and optimize solar cells by applying semiconductor principles to improve parameter's like I-V characteristics, efficiency, I_{SC}, V_{OC} and FF.
CO3:	Distinguish and analyze various solar cell technologies and photovoltaic systems including BOS components.
CO4:	Evaluate the design, size and cost of photovoltaic systems for recommending optimal solutions.

Note: Attempt all questions. All symbols have their usual meanings.

1. (a) Define sheet resistance. What is its units?
   (b) If the finger spacing between contacts is reduced to half, then power loss in emitter region is_____ to_____ %.
   (c) Explain with mathematical equations, the effect of increasing series and decreasing shunt resistance on the I-V characteristics of solar cells.
   (d) What are the different components of series resistance in a solar cell? Explain with a diagram and indicate the direction of charge flows.

[CO1 (Understanding), 1 + 1 + 2 + 2 = 6 Marks]

2. (a) Three different solar cells design are shown in the figure below. Which of the following has higher efficiency when light falls from (i) Top to bottom (ii) Left to right.



   (b) Explain any two methods to reduce the current loss and voltage loss due to recombination's of charge carriers in solar cells.
   (c) What is BSF in solar cells? How is it created and what are its applications?
   (d) State different methods to reduce the optical losses in solar cells. Calculate the minimum thickness required of the ARC for obtaining the minimum reflection form an encapsulated surface of Si solar cell at 550 nm. Given: $n_{si} = 3.8$ and $n_{glass} = 1.5$.

[CO2 (Applying), 2 x 4 = 8 Marks]

3. (a) Calculate the efficiency and peak power of Si solar cell of area 100 cm^2, operating under standard illumination of 1000 W/m^2 at 50 °C. Given at 27°C: $I_{SC} = 2$ A, FF = 70 % and $I_o = 1$ pA.
   (b) Calculate the total power loss and fractional power loss in the emitter region of Si solar cell of area 100 cm^2, if length = 10 cm, width = 10 cm, sheet resistance = 50 Ω/□, peak current = 2A, peak voltage = 0.5 V, spacing between fingers = 2 mm, and width of fingers = 0.1 mm and width of bus bar = 2.5 mm.

[CO2 (Applying), 3 x 3 = 6 Marks]

Date .....

Photovoltaic T3 Max

(36)

① Solar Cells ⇒ Connected in series/parallel (Module) ⇒ Connected in series/parallel (Array)

② I-V Equation:

$$I = I_L - I_0 \left[\exp\left[\frac{q(V + IR_s)}{nkT} \right] - 1 \right]$$

$$V_a = -I_a \frac{N_s R_s}{N_p} + N_s K \ln\left(\frac{N_p I_L - I_a + N_p I_0}{N_p I_0} \right)$$

$$(\text{Power})_{peak} = I_{sc} V_{oc} FF$$

where: FF = fill factor
I_{sc}, V_{oc} of whole array

where: N_s = no. of cells in series
N_p = no. of rows in parallel
$K = \frac{nkT}{q} = n \times 0.026$

③ In Series : Volt adds up , Curr is same (most min. one)
In Parallel : Volt is same , Curr adds up

④ PV Design (Water Question):

Step 1 : Find water requirmat : 1000 L = $1 m^3$

Step 2 : Find TDH = Total vertical lift + n% of vertical lift (Depth + Elevation)*

Step 3 : Find Hydraulic Energy = Density (1000 kg/m³) × Volume × g × TDH × $\frac{1}{3600}$
↳ wh/day

Step 4 : Find Insolation / Radiation = 1000 W/m² for 6h /day

Step 5 : Find No. of PV Panels = $\frac{\text{Hydraulic Energy}}{\text{Radiation hour}} \times \frac{1}{\text{pump x minute}} \times \frac{1}{\text{operation}}$

finally = $\frac{1}{\text{PV Rating}}$

⑤ Wire Question (Volt drop & Power Loss):

Volt drop = $V_d = 2 I \frac{\rho L}{A}$

where: ρ = resistivity of wire , L = dis b/w PV & battery
A = cross-sec-area of wire

Power Loss = $I^2 R$ → Just multiply I in this eq^n

as "R" is calculated w/ "2xL" hence the "2" in the eq^n

(iii) Given: 6 rows of module in parallel

2 modules in series for each row

36 cells, $R_s = 0.01\Omega$, $I_L = 1A$, $I_{sc} = 0.5A$, $V_{oc} = 0.6V$,

$I_0 = 1.5 \times 10^{-6} A$, temp = 25°C, $n = 1.2$

To find: (a) I-V eqn

(b) I_{sc}, V_{oc}

(c) Peak Power

Soln: (a) We know that:

$$V_a = -I_a \frac{N_s R_s}{N_p} + N_s K \ln\left(\frac{N_p I_L - I_a + N_p I_0}{N_p I_0}\right) \quad \text{--- (1)}$$

N_s = no. of cells in series = 2×36

N_p = no. of rows in ‖ = 6

$K = n \frac{kT}{q} = n \times 0.026$

$$V_a = -I_a \frac{2 \times \cancel{36}^{6} \times 0.01}{6} + 2 \times 36 \times 1.2 \times 0.026 \ln\left(\frac{6(1) - I_a + 9 \times 10^{-6}}{9 \times 10^{-6}}\right)$$

$$\boxed{V_a = -I_a (0.12) + 2.24 \ln\left(\frac{6 - I_a}{9 \times 10^{-6}}\right)}$$

(b) V_{oc} of 1 cell = 0.6 V

V_{oc} of 36 cells = $0.6V \times 36$

V_{oc} of 2 modules = $0.6 \times 36 \times 2$ = $\boxed{43.2 V}$

I_{sc} of 1 cell = 0.5 A

I_{sc} of 6 rows = $\boxed{\frac{6}{2} = 3A}$

(c) $\boxed{\text{Peak Power} = I_{sc} V_{oc} FF = \cancel{12.96}\ 129.6 W}$

② Given: $R_{eq} = 10000\,L = 10\,m^3$ ($1\,m^3 = 1000\,L$)

Depth = 20m, ele = 5m, fric = 10%, density = 1000 kg/m³

$g = 9.8\,m/s^2$, PV = 75 Wp, Op fac = 0.75, pump = 25%

mismatch = 0.75, solar = 1000 W/m² for 6h/day

To find: Design the system

TDH = depth + elevation + 10% (fric)
or first then number that is given? Check notes

Sol^n: Step 1: $R_{eq} = 10{,}000\,L = 10\,m^3/day$ — (i)

Step 2: TDH = 20m + 10%(20) = 22m — (ii)

Step 3: Hydraulic Energy = Density × Volume × g × TDH $= 1000 \times 10 \times \frac{9.8}{3600} \times 22$

$E_h = 598.8$ Wh/day — (iii)

Step 4: ~~No. of Panels~~ Insolation Radiation = 1000 W/m² for 6h/day

Step 5: No. of Panels = $\frac{\text{Energy Hydraulic}}{\text{Energy Sol}} = \frac{598.8}{6} = 99.81\,W$

Considering pump eff, mismatch $= \frac{99.81}{0.25(0.75)} = 532.34\,W$

Considering op fac $= \frac{532.34}{0.75} = 709.79\,W$

No. of Panels $= \frac{709.79}{PV\ rating} = \frac{709.79}{75} = 9.46 \approx$ 10 panels / 10 panels

Spiral

① Given: distance = 10m To find: Volt Drop

Volt = 12 V if area = 1.5 mm²

Area = 2.5 mm²

Curr = 3.5A , $\rho = 1.678 \times 10^{-8}\ \Omega m$

Sol^n:

$$V_d = 2 \cdot I \frac{\rho L}{A} = 2 \times 3.5 \times \frac{1.678 \times 10^{-8} \times 10}{2.5 \times (10^{-3})^2}$$

$$= 0.469\ V$$

Converting to %:

x % 12 = 0.469

$$x = \frac{0.469}{12} \times 100 = 3.9\%$$

∵ it lies under 5%
∴ acceptable

If area = 1.5 mm²

$$\therefore V_d = 2(3.5) \frac{1.678 \times 10^{-8} \times 10}{1.5 \times 10^{-6}} = 0.783\ V$$

n % of 12 = 0.783

$$n = \frac{0.783}{n} \times 100 = 6.5\%$$

⇒ hence not acceptable

② Given: L = 10 cm = 0.1 m

V = 12 V , I = 3.5 A , A = 1.5 mm² , $\rho = 1.678 \times 10^{-8}\ \Omega m$

To find: V_d, P_{loss}

Sol^n:

$$V_d = 2 I \frac{\rho L}{A} = 2 \times 3.5 \times \frac{1.678 \times 10^{-8} \times 0.1}{1.5 \times 10^{-6}}$$

$$= 7.83 \times 10^{-3}\ V$$

$$= 0.065\ \%$$

↳ acceptable

$$P_{loss} = I^2 R = I^2 \frac{\rho L}{A}$$

~~= 0.047 W~~

$$= 0.0274\ W$$