Subject Name Solutions

1313202 – Summer 2023

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Find mesh currents in following circuit.

Solution

Diagram/Table:

```
      2Ωk        2Ωk







          1Ωk
5V                  2V



```

Applying Mesh Analysis:

- Write KVL equations for two meshes
- I$_1 flowsclockwiseinleftloop$
- I$_2 flowsclockwiseinrightloop$

Steps to solve:

- **Mesh 1 equation**: 5V - 2kΩ$_1 - 1k \times (I_1 - I_2) = 0$
- **Mesh 2 equation**: -2V + 2kΩ$_2 + 1k \times (I_2 - I_1) = 0$

Simplifying:

- 5 - 2000I$_1 - 1000I_1 + 1000I_2 = 0$
- -2 + 2000I$_2 + 1000I_2 - 1000I_1 = 0$
- 3000I$_1 - 1000I_2 = 5$
- -1000I$_1 + 3000I_2 = 2$

Solving: I$_1 = 2mAI_2 = 1mA$

Mnemonic

"Mesh Matters: Write KVL, Solve Simultaneous"

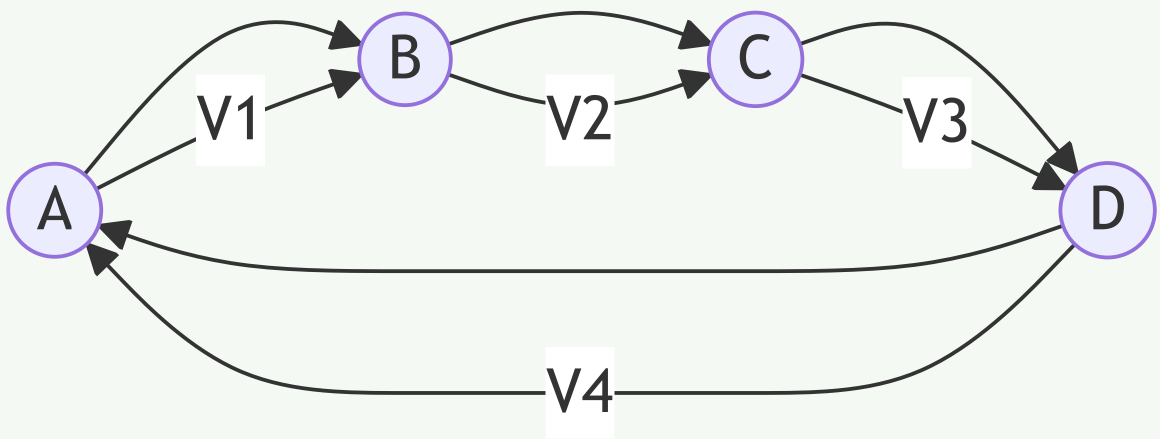
Question 1(b) [4 marks]

State and explain Kirchhoff's Voltage Law (KVL) with the help of diagram.

Solution

Kirchhoff's Voltage Law (KVL) states that the algebraic sum of all voltages around any closed loop in a circuit is zero.

Diagram:



Key points:

- **Loop rule**: $\mathrm{V}_1 + V_2 + V_3 + V_4 = 0$
- **Sign convention**: Voltage rise (battery positive terminal) is positive, voltage drop (across resistor) is negative
- **Conservation principle**: Total energy gained equals total energy lost in any closed loop
- **Application**: Used to analyze and solve complex circuits with multiple voltage sources

Mnemonic

"Voltages Around a Loop Sum to Zero" (VALSZ)

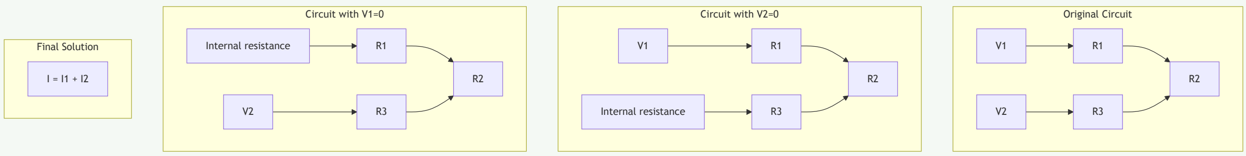
Question 1(c) [7 marks]

State and explain Superposition theorem.

Solution

Superposition theorem states that in a linear circuit with multiple sources, the response in any element is the sum of responses caused by each source acting alone, with all other sources replaced by their internal impedances.

Diagram:



Steps to apply:

- **Step 1**: Consider one source at a time
- **Step 2**: Replace voltage sources with short circuits (0Ω)
- **Step 3**: Replace current sources with open circuits ()
- **Step 4**: Calculate the response (voltage/current) due to each source
- **Step 5**: Add all responses algebraically to get total response

Applications:

- **Circuit analysis**: Simplifies complex circuits with multiple sources
- **Network theory**: Foundation for more advanced analysis methods
- **Practical circuits**: Analyzing superimposed signals in communication systems

Mnemonic

"Sources Separately, Sum Successfully" (SSSS)

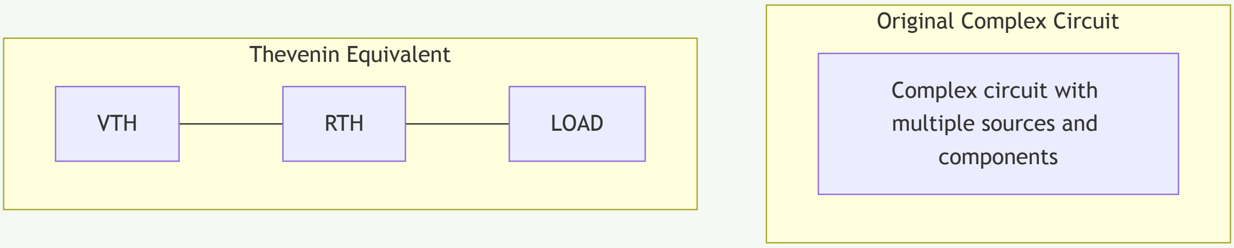
Question 1(c) OR [7 marks]

State and explain Thevenin's theorem.

Solution

Thevenin's theorem states that any linear circuit with voltage and current sources can be replaced by an equivalent circuit consisting of a voltage source (VTH) in series with a resistance (RTH).

Diagram:



Steps to find Thevenin equivalent:

- **Step 1**: Remove load resistor from original circuit
- **Step 2**: Calculate open-circuit voltage (VOC) across load terminals (= VTH)
- **Step 3**: Calculate equivalent resistance (RTH) by:
  - Deactivating all sources (replacing voltage sources with short circuits and current sources with open circuits)
  - Finding resistance between load terminals

Applications:

- **Circuit simplification**: Reduces complex networks to simple equivalent
- **Load analysis**: Easily calculate effects of changing loads
- **Maximum power transfer**: Determine conditions for maximum power

Mnemonic

"Two Handy Elements: Voltage and Resistance" (THEVR)

Question 2(a) [3 marks]

Give comparison of trivalent, tetravalent and pentavalent materials.

Solution

Property	Trivalent Materials	Tetravalent Materials	Pentavalent Materials
Valence electrons	3	4	5
Examples	Boron, Aluminum, Gallium	Silicon, Germanium, Carbon	Phosphorus, Arsenic, Antimony
Doping type	Used as P-type dopants	Base semiconductor materials	Used as N-type dopants
Bond formation	Makes 3 covalent bonds	Makes 4 covalent bonds	Makes 5 covalent bonds
Charge carriers	Creates holes (positive)	Creates balanced structure	Creates free electrons (negative)

Mnemonic

"Three-Four-Five: Holes-Balance-Electrons" (TFF:HBE)

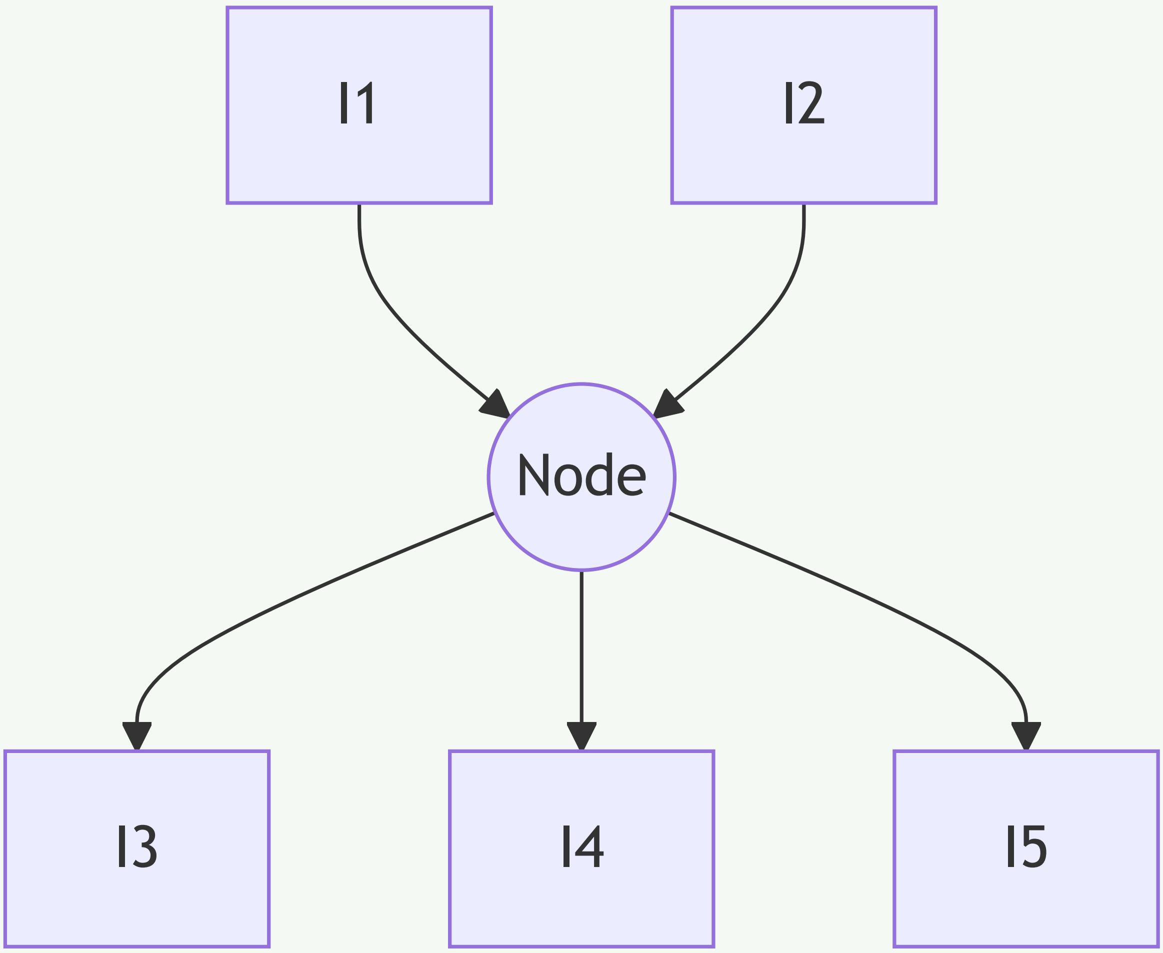
Question 2(b) [4 marks]

State and explain Kirchhoff's Current Law (KCL) with the help of diagram.

Solution

Kirchhoff's Current Law (KCL) states that the algebraic sum of all currents entering and leaving any node in an electrical circuit is zero.

Diagram:



Key points:

- **Node equation**: $\mathrm{I}_1 + I_2 - I_3 - I_4 - I_5 = 0 (or I_1 + I_2 = I_3 + I_4 + I_5)$
- **Sign convention**: Currents entering node are positive, leaving are negative
- **Conservation principle**: Based on conservation of electric charge
- **Application**: Essential for solving circuits with parallel components

Mnemonic

"Currents In Equals Currents Out" (CIECO)

Question 2(c) [7 marks]

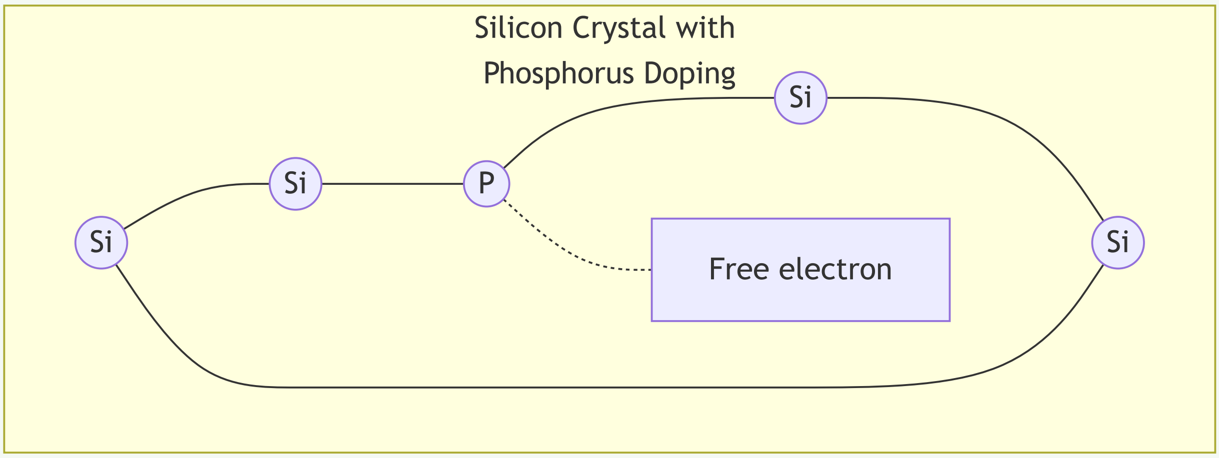
Define: Extrinsic Semiconductor. Explain formation of N-type Semiconductor with the help of diagram.

Solution

Extrinsic Semiconductor: A semiconductor whose electrical properties are modified by adding impurity atoms (doping) to change its conductivity.

N-type Semiconductor Formation:

Diagram:



Process:

- **Doping process**: Pentavalent impurity (P, As, Sb) added to tetravalent semiconductor (Si, Ge)
- **Bond formation**: Impurity atom forms 4 covalent bonds with neighboring Si atoms
- **Free electron**: 5th electron has no bond to form and becomes free to move
- **Charge carriers**: Majority carriers are electrons, minority carriers are holes
- **Conductivity**: Higher than intrinsic semiconductor due to more free electrons

Properties of N-type semiconductor:

- **Fermi level**: Closer to conduction band
- **Donor level**: Energy level created near conduction band
- **Room temperature**: Most donor atoms are ionized

Mnemonic

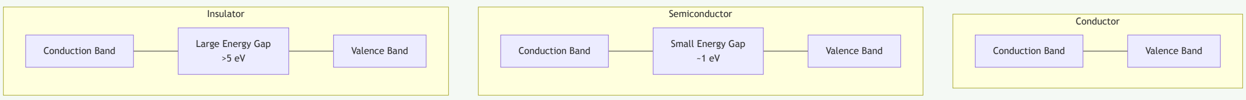
"Phosphorus Provides Plus-one electron" (PPP)

Question 2(a) OR [3 marks]

Draw energy band diagrams for Conductor, Semiconductor and Insulator.

Solution

Diagram:



Key characteristics:

- **Conductor**: Overlapping bands or partially filled band
- **Semiconductor**: Small energy gap (~1 eV)
- **Insulator**: Large energy gap (>5 eV)

Mnemonic

"Gaps Determine Flow: None, Small, Huge" (GDF:NSH)

Question 2(b) OR [4 marks]

Give the difference between EMF and Potential difference.

Solution

Parameter	EMF (Electromotive Force)	Potential Difference
Definition	Energy supplied per unit charge by a source	Energy consumed per unit charge in a component
Symbol & Unit	or E, measured in Volts	V, measured in Volts
Cause	Chemical, mechanical, thermal or light energy conversion	Result of current flowing through a resistance
Measurement	Measured across source terminals with no current flowing	Measured across components when current flows
Direction	From negative to positive inside source	From positive to negative outside source
Device example	Battery, generator, solar cell	Resistor, lamp, motor
Conservation	Not conserved in a circuit	Conserved in a closed circuit (KVL)

Mnemonic

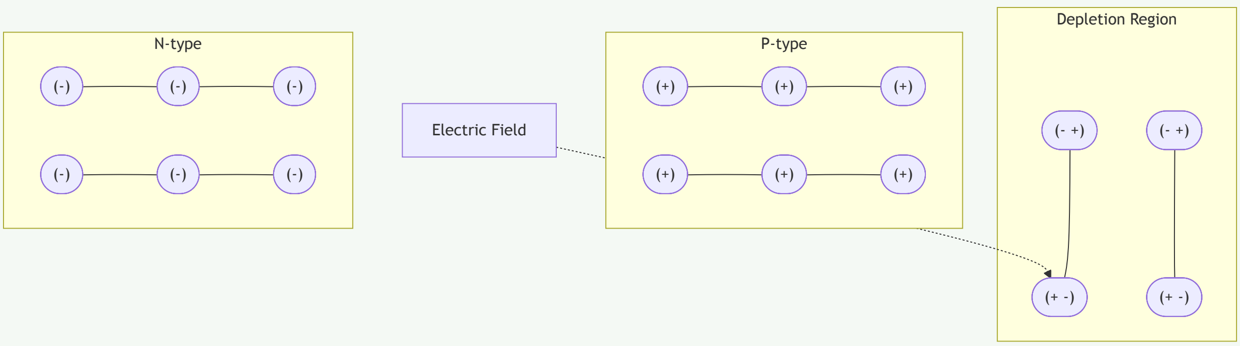
"EMF Creates, PD Consumes" (ECPC)

Question 2(c) OR [7 marks]

Explain the formation of depletion region or space-charge region in P-N junction.

Solution

Diagram:



Formation process:

- **Junction creation**: When P-type and N-type semiconductors are joined
- **Diffusion**: Free electrons from N-side diffuse to P-side; holes from P-side diffuse to N-side
- **Recombination**: Electrons recombine with holes near junction
- **Ion formation**: Immobile positive ions left in N-region; negative ions in P-region
- **Electric field**: Created across the junction pointing from N to P
- **Equilibrium**: Diffusion current balanced by drift current due to electric field
- **Barrier potential**: Typically 0.7V for silicon, 0.3V for germanium

Characteristics:

- **Width**: Typically 0.5 m, depends on doping concentration
- **Capacitance**: Acts as variable capacitor
- **Barrier**: Prevents further diffusion of majority carriers

Mnemonic

"Diffusion Creates, Field Balances" (DCFB)

Question 3(a) [3 marks]

Define forbidden energy gap. How does it occur? What is its magnitude for Ge and Si?

Solution

Forbidden energy gap is the energy range between valence band and conduction band where no electron energy states exist in a semiconductor.

Occurrence:

- Results from quantum mechanical interaction of atoms in crystal lattice
- Forms due to splitting of energy levels when atoms are brought close together
- Creates band structure with allowed and forbidden regions

Magnitude:

- **Germanium (Ge)**: 0.67 eV at 300K
- **Silicon (Si)**: 1.1 eV at 300K

Mnemonic

"Greater Silicon, Lower Germanium" (GSLG)

Question 3(b) [4 marks]

Define the following terms: (i) Knee voltage (ii) Reverse saturation current (iii) Reverse breakdown voltage (iv) Peak Inverse Voltage (PIV)

Solution

Table of Definitions:

Term	Definition
Knee voltage	The forward voltage at which current through diode starts increasing rapidly (0.3V for Ge, 0.7V for Si)
Reverse saturation current	The small current that flows when diode is reverse biased, due to minority carriers (typically nA or A)
Reverse breakdown voltage	The reverse voltage at which the diode conducts heavily in reverse direction due to breakdown mechanisms
Peak Inverse Voltage (PIV)	Maximum reverse voltage a diode can withstand without breakdown in a rectifier circuit

Mnemonic

"Knee Rises, Saturation Trickles, Breakdown Bursts, PIV Protects" (KRSBBP)

Question 3(c) [7 marks]

Explain construction, working and characteristics of LASER diode and write its applications.

Solution

Diagram:

```
                  +--------+
+---------+       |        |
| p-type  |~~~~~~~~|        |----> Laser Beam
+---------+       |        |
| active  |~~~~~~~~|        |
| layer   |       |        |
+---------+       |        |
| n-type  |~~~~~~~~|        |
+---------+       |        |
                  +--------+
                Reflective Surfaces
```

Construction:

- **P-N junction**: Made of direct bandgap semiconductor (GaAs, InGaAsP)
- **Active region**: Thin layer between P and N regions where recombination occurs

- **Cavity design**: Parallel reflective surfaces (cleaved facets) form optical resonator
- **Packaging**: Includes heat sink, optical window, monitoring photodiode

Working principle:

- **Injection**: Forward biasing injects electrons and holes into active region
- **Population inversion**: More electrons in excited state than ground state
- **Stimulated emission**: Photon triggers release of identical photons (same wavelength, phase)
- **Optical feedback**: Photons reflect between mirrors, amplifying light
- **Threshold current**: Minimum current for lasing action

Characteristics:

- **Coherent light**: Single wavelength, in-phase light emission
- **Directionality**: Highly directional, narrow beam
- **High intensity**: Concentrated energy output
- **Threshold behavior**: Laser action only above threshold current

Applications:

- Optical fiber communications
- DVD/Blu-ray players
- Laser printers
- Barcode scanners
- Medical surgery instruments

Mnemonic

"Population Inversion Creates Coherent Light" (PICL)

Question 3(a) OR [3 marks]

Draw V-I characteristics of P-N junction diode and Zener diode.

Solution

Diagram:

```
   ↑I
    |                /
    |               /
    |              /
    |             /
    |            /
Forward |            /
    |          /
    |         /         P-N Junction Diode
    |        /
    |       /
----+-------------------- V \rightarrow
    |      /
    |     /
    |    /
Reverse|
    |
    |
    |                    Zener
    |                    Breakdown
    |                    Region
    |                      |
    |                    \ |
    |                     \|
    |                      |
    |                      |
    |                      v

   ↑I
    |                /
    |               /
    |              /
```

```
     |               /
     |              /
Forward |              /
     |            /
     |           /         Zener Diode
     |          /
     |         /
----+-------------------- V \rightarrow
     |        /
     |       /
     |      /
Reverse|
     |       ------
     |      /
     |     /
     |    /         Zener
     |   /          Region
     |  /
     | /
     |/
```

Key differences:

- **P-N Junction diode**: Conducts in forward bias, blocks in reverse until breakdown
- **Zener diode**: Specially designed to operate in reverse breakdown region at precise voltage

Mnemonic

"Forward Same, Reverse Different" (FSRD)

Question 3(b) OR [4 marks]

Explain working of P-N junction diode in forward bias with circuit diagram.

Solution

Diagram:

```
        +
    V   |      R
    ___/\/\/\__
   |            |
   |            |
   |    |>|     |
   |    D1      |
   |            |
   |____________|
        -
```

Working in forward bias:

- **Connection**: P-side connected to positive terminal, N-side to negative terminal
- **Depletion region**: Width decreases as applied voltage increases
- **Barrier potential**: Must overcome threshold (0.7V for Si, 0.3V for Ge)
- **Current flow**: Above threshold, current increases exponentially with voltage
- **Majority carriers**: Electrons from N-side and holes from P-side are pushed toward junction
- **Recombination**: Electrons and holes recombine, creating continuous current flow

Current equation: I = $I_0(e\hat{}(qV/kT) - 1), where I_0 is reverse saturation current$

Mnemonic

"Positive to P, Reduces Barrier, Current Flows" (PPRBCF)

Question 3(c) OR [7 marks]

Explain working of Light Emitting diode (LED) and Photodiode with diagram.

Solution

LED Diagram:

```
     Current
       flow
        ↓
    +-------+
    |       |
+---+       +---+
|   | P-type|   |
|   +-------+   |
|   | N-type|   |
|   |       |   |
+---+       +---+
    |       |
    +-------+
       ↑
     Photon
    Emission
```

LED Working:

- **Direct bandgap**: Made of GaAs, GaP compounds with direct bandgap
- **Forward bias**: Applied to inject carriers across junction
- **Recombination**: Electrons from N-side recombine with holes from P-side
- **Photon emission**: Energy released during recombination emitted as photons
- **Wavelength control**: Different materials produce different colors
- **Efficiency**: Modern LEDs achieve 80-90% efficiency

Photodiode Diagram:

```
    +-------+
    |       |
+---+       +---+
|   | P-type|   |
|   +-------+   |
|   | N-type|   |
|   |       |   |
+---+       +---+
    |       |
    +-------+
       ↑
     Photon
    Absorption
```

Photodiode Working:

- **Reverse bias**: Operated in reverse bias typically
- **Light absorption**: Photons absorbed in depletion region
- **Electron-hole pairs**: Created by photon energy
- **Carrier separation**: Electric field separates electrons and holes
- **Current generation**: Photocurrent proportional to light intensity
- **Response time**: Faster in reverse bias due to wider depletion region

Comparison table:

Parameter	LED	Photodiode
Function	Converts electrical energy to light	Converts light to electrical energy
Bias mode	Forward bias	Reverse bias (typically)
Direction	Energy output (emitter)	Energy input (detector)
Application	Displays, indicators, lighting	Light sensors, optical communications

Mnemonic

"LEDs Emit, Photodiodes Detect" (LEPD)

Question 4(a) [3 marks]

Define the following terms: (i) Rectifier efficiency ( ) (ii) Ripple factor ( ) (iii) Voltage regulation

Solution

Table of Definitions:

Term	Definition
Rectifier efficiency ( )	Ratio of DC power output to AC power input in a rectifier circuit (= P_DC/P_AC ×100%)
Ripple factor ( )	Ratio of RMS value of AC component to DC component in rectifier output (= V_rms(ac)/V_dc)
Voltage regulation	Measure of how well a power supply maintains constant output voltage despite changes in load (VR = [(V_NL - V_FL)/V_FL] ×100%)

Mnemonic

"Efficiency Powers, Ripple Varies, Regulation Stabilizes" (EPRVS)

Question 4(b) [4 marks]

Explain zener diode as a voltage regulator.

Solution

Diagram:

```
    R
   /\/\/\
Vi +----+----+ Vout
    |    |    |
    |   [Z]   RL
    |    |    |
    +----+----+
         -
```

Working principle:

- **Zener breakdown**: Operates in reverse breakdown region at specific voltage
- **Series resistor**: Limits current and drops excess voltage
- **Parallel connection**: Zener connected in parallel with load
- **Regulation mechanism**:
  - When input voltage increases: More current through Zener, voltage across load remains constant
  - When load current increases: Less current through Zener, voltage remains constant

Characteristics:

- **Load regulation**: Maintains constant voltage despite load changes
- **Line regulation**: Maintains constant voltage despite input voltage changes
- **Power rating**: Zener must handle maximum power dissipation (P = V_Z ×*I_Z*)
- **Design equation**: R = (V_in - V_Z)/I_L + I_Z)

Mnemonic

"Zener Shunts Excess Current" (ZSEC)

Question 4(c) [7 marks]

Explain full wave bridge rectifier with circuit diagram and input-output waveform.

Solution

Circuit Diagram:

```
         D1        D3
         |>|       |>|
          |         |
Vin ------+----+----+----- Vout
          |    |    |
          |    RL   |
          |    |    |
          +----+----+
         |>|       |>|
         D2        D4
```

Working principle:

- **First half cycle (positive)**: D1 and D4 conduct, D2 and D3 block
- **Second half cycle (negative)**: D2 and D3 conduct, D1 and D4 block
- **Both half cycles**: Current flows through load in same direction

Waveforms:

```
Input:         Output:
    ^              ^
    |              |
    |  /\    /\    |   /\    /\    /\
    | /  \  /  \   |  /  \  /  \  /  \
----+------+---+---+-+-----+----+----+-->
    |       \  /   |
    |        \/    |
    |              |
    v              v
```

Characteristics:

- **Ripple frequency**: Twice the input frequency
- **Output voltage**: V_dc = 2V_m/ $\approx 0.636V\_m$
- **PIV**: Each diode must withstand V_m
- **Efficiency**: $= 81.2\%$
- **Ripple factor**: $= 0.48$
- **Uses**: Higher current applications, no center-tapped transformer needed

Advantages over center-tapped:

- No center-tapped transformer required
- Lower PIV requirement for diodes
- Better transformer utilization

Mnemonic

"Bridge Brings Both Halves" (BBBH)

Question 4(a) OR [3 marks]

Give the applications of rectifier.

Solution

Applications of Rectifiers:

Application Area	Specific Uses
Power supplies	DC power supplies for electronic devices, battery chargers, adaptors
Industrial applications	Electroplating, welding machines, motor drives, induction heating
Transport systems	Electric locomotives, metro trains, electric vehicles
Renewable energy	Solar inverters, wind power generation

Consumer electronics	Mobile phone chargers, laptop adapters, TV power supplies
Telecommunications	Base stations, transmission equipment, signal processing devices

Mnemonic

"Power Perfectly Transformed in Consumer Devices" (PPTICD)

Question 4(b) OR [4 marks]

Compare half wave, full wave center tapped and full wave bridge rectifier with four parameters.

Solution

Parameter	Half Wave	Full Wave Center Tapped	Full Wave Bridge
Number of diodes	1	2	4
DC output voltage	V_m/ (0.318V_m)	2V_m/ (0.636V_m)	2V_m/ (0.636V_m)
Ripple frequency	Same as input	Twice the input	Twice the input
Efficiency	40.6%	81.2%	81.2%
Transformer utilization	Poor	Medium (center tap needed)	Good (no center tap)
PIV of diodes	V_m	2V_m	V_m
Ripple factor	1.21	0.48	0.48
Form factor	1.57	1.11	1.11

Mnemonic

"Half Wastes, Center Tapped Improves, Bridge Optimizes" (HWCTIBO)

Question 4(c) OR [7 marks]

Explain Shunt capacitor filter and -filter with circuit diagram.

Solution

Shunt Capacitor Filter:
Diagram:

```
      Rectifier   C
          |       |
Vin --->|M|-------+------ Vout
          |       |
          |       RL
          |       |
          +-------+------
```

Working principle:

- **Charging**: Capacitor charges rapidly during voltage rise in rectifier output
- **Discharging**: Capacitor discharges slowly through load during voltage fall
- **Smoothing effect**: Reduces ripple by storing energy when voltage is high
- **Time constant**: RC should be much larger than ripple period
- **Performance**: Ripple factor $= 1/(4\sqrt{3}fRC)$

-Filter:
Diagram:

```
      Rectifier    L
```

```
         |       /\/\/\
Vin --->|M|-------+------ Vout
         |        |
         |        |
         |        |
         +---||---+---||--+
             C1       C2  |
             |        |   RL
             |        |   |
             +--------+---+
```

Working principle:

- **First capacitor (C1)**: Provides initial filtering like shunt capacitor
- **Choke (L)**: Blocks AC components, allows DC to pass
- **Second capacitor (C2)**: Further reduces remaining ripple
- **Combined effect**: Acts as cascade of low-pass filters

Comparison:

Parameter	Shunt Capacitor Filter	-Filter
Components	Single capacitor	Two capacitors and inductor
Ripple reduction	Moderate	Excellent
Cost	Low	High
Size	Small	Large
Voltage regulation	Poor	Good
Suitable for	Low current applications	High current applications

Mnemonic

"Capacitor Smooths, Pi-Filter Perfects" (CSPFP)

Question 5(a) [3 marks]

Draw the symbols of following components: (i) PNP transistor (ii) N channel JFET (iii) N channel enhancement mode MOSFET

Solution

Diagram:

```
PNP Transistor:       N-channel JFET:      N-channel enhancement MOSFET:
     C                     D                        D
     |                     |                        |
     |                     |                        |
  >--+                     +---<                    |
 /    \                   /|                        |
|  E   |                 / |                     +--+
 \    /                 /  |                     |  |
  +--+--B              /   |                 G---+  |
  |                    |   |                     |  |
  |                 G--+   +--S                  +--+--S
  E                    |                            |
                       |                            |
                       S
```

Characteristics:

- **PNP Transistor**: Arrow points inward at emitter
- **N-channel JFET**: Gate controls channel between source and drain
- **N-channel enhancement MOSFET**: Gap in channel, requires positive gate voltage

Mnemonic

"PNP Points IN, JFET Joins Gates, MOSFET Makes Gaps" (PPIJJGMMG)

Question 5(b) [4 marks]

Explain working of NPN transistor with diagram.

Solution

Diagram:

```
       Collector (C)
           |
           |
   +-----------------+
   |      N-type     |
   +-----------------+
   |      P-type     |
   +-----------------+
   |      N-type     |
   +-----------------+
           |
           |
       Emitter (E)

 B---/\/\/\--+   +--/\/\/\--C
   (RB)      |   |  (RC)
             |   |
            V_BE|   V_CE
     +-------|---+-------+
     |       |           |
     |       +--[NPN]----+
     |          |        |
     |          |        |
     +----------+--------+
                |
                |
                E
```

Working principle:

- **Structure**: Two N-type regions separated by thin P-type region
- **Biasing**: E-B junction forward biased, C-B junction reverse biased
- **Current flow**:
  - Electrons from emitter cross into base
  - ~98% electrons continue to collector due to thin base region
  - ~2% electrons recombine in base region
- **Amplification**: Small base current controls larger collector current
- **Current relationship**: I_C = $\times I\_B(whereiscurrentgain)$

Junction behavior:

- **Emitter-Base junction**: Forward biased, low resistance path
- **Collector-Base junction**: Reverse biased, high resistance path

Mnemonic

"Electrons Enter, Barely Pause, Collect Above" (EEBPCA)

Question 5(c) [7 marks]

Draw and explain common emitter (CE) transistor with its input output characteristic.

Solution

Circuit Diagram:

```
     +VCC
      |
      R_C
      |
      +-----o V_out
      |
      |
  B---+--[NPN]
  |      |
  R_B    |
  |      |
  +      E
V_in     |
  -      |
 GND    GND
```

Input Characteristics (I_B vs V_BE with V_CE constant):

```
  I_B ↑
   |
   |            V_CE = 10V
   |           /
   |          /
   |         / V_CE = 5V
   |        /
   |       /
   |      /
   |     /
   |    /
   |   /
   |  /
   | /
   |/
  +---------------> V_BE
      0.7V
```

Output Characteristics (I_C vs V_CE with I_B constant):

```
  I_C ↑
   |                   I_B =  50A
   |                 /-----------
   |                /
   |               /  I_B =  40A
   |              /------------
   |             /
   |            /   I_B =  30A
   |           /--------------
   |          /
   |         /    I_B =  20A
   |        /---------------
   |       /
   |      /     I_B =  10A
   |     /----------------
   |    /
   |   /      I_B = 0
   |  /------------------
   | /
   |/
  +--+-----+----------> V_CE
     |     |
   Saturation|Active
     Region |Region
```

Operating regions:

- **Cut-off**: I_B $\approx 0, I\_C \approx 0, transistorOFF$

- **Active**: E-B junction forward biased, C-B junction reverse biased, linear amplification
- **Saturation**: Both junctions forward biased, transistor fully ON

Parameters:

- **Current gain ( )**: Ratio of collector current to base current (= I_C/I_B)
- **Input resistance**: Ratio of change in V_BE to change in I_B
- **Output resistance**: Ratio of change in V_CE to change in I_C

Applications:

- **Amplification**: Voltage, current, and power amplification
- **Switching**: Digital circuits, logic gates
- **Signal processing**: Oscillators, filters, modulators

Mnemonic

"Cut-Active-Saturate: Off-Amplify-On" (CASOAO)

Question 5(a) OR [3 marks]

Derive relationship between current gain alpha ( ) and beta ( ).

Solution

Key definitions:

- **Alpha ( )**: Common-base current gain = I_C/I_E
- **Beta ( )**: Common-emitter current gain = I_C/I_B

Diagram:

```
        I_C
        ^
        |
    +----+----+
    |         |
I_E >    T    > I_B
    |         |
    +---------+
```

Current relationship in transistor:

- I_E = I_B + I_C (Kirchhoff's Current Law)

Derivation steps:

1.   = I_C/I_E
2. I_E = I_B + I_C
3.   = I_C/(I_B + I_C)
4.   = I_C/I_B
5. I_C = $\times I\_B$
5. Substituting in equation 3:
     = ($\times I\_B)/(I\_B + \times I\_B)$

  = /(1
+)

6. Solving for : (1 +) =   +   =

  = -
  = (1 -)
  =
/(1 -)

Final relationships:

-   = /(1 -)
-   = /(1 +)

Typical values:

-   is always less than 1 (typically 0.95 to 0.99)
-   typically ranges from 20 to 200

Mnemonic

"Alpha Approaches One, Beta Becomes Infinite" (AAOBBI)

Question 5(b) OR [4 marks]

Explain different operating regions for transistor.

Solution

Diagram:

```
  I_C ↑
    |
    |      +-------------+
    |      |             |
    |      |             |
    |      |             |
    |      |   Active    |
    |      |   Region    |
    | Saturation         |
    | Region|            |
    |      |             |
    |      |             |
    |      |             |
    +------+-------------+-------> V_CE
    |                    |
    |                    |
    |    Cut-off Region  |
    |                    |
    |                    |
    +--------------------+
```

Operating regions:

Region	Junction Bias	Characteristics	Applications
Cut-off	E-B: OFFC-B: OFF	• I_B ≈ 0, $I\_C \approx 0 Transistor is OFF V\_CE \approx V\_CC$	Digital circuits (OFF state)Switching applications
Active	E-B: ONC-B: OFF	• Linear relationship between I_C and I_B • I_C = $\times I\_B Used for amplification$	Analog amplifiersSignal processing
Saturation	E-B: ONC-B: ON	• Both junctions forward biased • Transistor fully ON • V_CE ≈ $0.2V$	Digital circuits (ON state)Switching applications
Breakdown	E-B: OFFC-B: Breakdown	• Exceeds breakdown voltage • Can damage transistor • Should be avoided	Avoid this region in normal operation

Mnemonic

"Cut Active Saturate: Off Amplify Switch" (CASOAS)

Question 5(c) OR [7 marks]

Write a short note on MOSFET.

Solution

MOSFET (Metal Oxide Semiconductor Field Effect Transistor)
Structure Diagram:

```
     Gate (G)
        |
        v
     +-----+    Drain (D)
     |  M  |      |
     +-----+      v
     |  O  |    +---+
```

```
+-----+    |   |
|  S  |    | N |
+-----+----+---+----+
|                   |
|        P          |
|                   |
+---+-------------+-+
    |             |
    v             v
Source (S)    Substrate
```

Types of MOSFETs:

- **Enhancement mode**: Channel does not exist without gate voltage
  - N-channel: Positive gate voltage creates channel
  - P-channel: Negative gate voltage creates channel
- **Depletion mode**: Channel exists without gate voltage
  - N-channel: Negative gate voltage depletes channel
  - P-channel: Positive gate voltage depletes channel

Working principle:

- **Insulated gate**: Gate isolated from channel by oxide layer
- **Field effect**: Electric field controls channel conductivity
- **Voltage controlled**: Gate voltage controls drain current
- **No gate current**: Extremely high input impedance

Characteristics:

- **Transfer characteristic**: I_D vs V_GS
- **Output characteristic**: I_D vs V_DS
- **Threshold voltage**: Minimum V_GS required to create channel
- **Transconductance**: Change in I_D per unit change in V_GS

Advantages over BJT:

- **High input impedance**: Virtually no input current
- **Faster switching**: Lower capacitance, no minority carrier storage
- **Higher packing density**: Smaller size for same function
- **Lower power consumption**: Less heat generation
- **Simpler biasing**: Single polarity supply often sufficient

Applications:

- **Digital circuits**: CMOS logic, memory devices
- **Analog circuits**: Amplifiers, current sources
- **Power electronics**: High-power switching
- **RF applications**: Low-noise amplifiers
- **Integrated circuits**: Processors, ASICs

Mnemonic

"Metal Oxide Separate Gate Enables Field Control" (MOSGFC)