Subject Name Solutions

1313202 – Winter 2023

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Explain difference between Active and passive network.

Solution

Active Network	Passive Network
Contains at least one energy source	Contains no energy source
Can deliver power to other elements	Cannot deliver power to other elements
Examples: Transistors, Op-amps, Batteries	Examples: Resistors, Capacitors, Inductors

Mnemonic

"Active Adds Power, Passive Pulls Power"

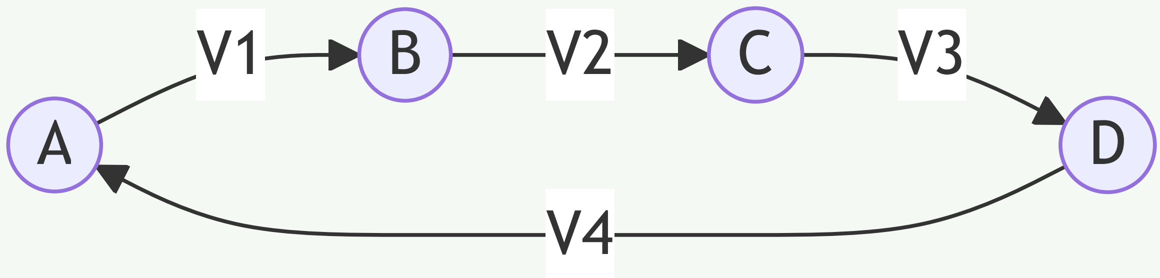
Question 1(b) [4 marks]

State and explain Kirchhoff's voltage law (KVL).

Solution

Kirchhoff's Voltage Law (KVL): The algebraic sum of all voltages around any closed path (loop) in a circuit is zero.

Diagram:



Mathematical Form: $V_1 + V_2 + V_3 + V_4 = 0$

- **Circuit Application**: When moving around a loop, voltage rises (batteries) are positive and voltage drops (components) are negative
- **Physical Meaning**: Total energy in a closed loop is conserved

Mnemonic

"Voltage Loop Sum Zero"

Question 1(c) [7 marks]

Define the following terms: (1) Charge (2) Current (3) Potential (4) E.M.F. (5) Inductance (6) Capacitance (7) Frequency.

Solution

Term	Definition
Charge	The basic electrical quantity measured in coulombs (C); flow of electrons creates electricity
Current	The rate of flow of electric charge, measured in amperes (A); I = dQ/dt
Potential	Electric potential energy per unit charge, measured in volts (V)
E.M.F.	Electromotive force, energy supplied by source per unit charge, measured in volts (V)
Inductance	Property of a conductor to oppose change in current, measured in henry (H)
Capacitance	Ability of a component to store electric charge, measured in farad (F)
Frequency	Number of cycles per second of an alternating quantity, measured in hertz (Hz)

Mnemonic

"Careful Currents Pass Easily Into Circuit Frequently"

Question 1(c) OR [7 marks]

State Ohm's law. Write its application and limitation.

Solution

Ohm's Law: The current flowing through a conductor is directly proportional to the potential difference across it and inversely proportional to its resistance.

Mathematical Form: I = V/R

Diagram:

```
            +
            |
            V
            |
  A---------/\/\/\---------B
            R
            |
            |
            -
```

Applications of Ohm's Law:

- Computing current, voltage, resistance in circuits
- Design of electrical networks
- Power calculations ($P = VI = I^2R = V^2/R$)
- Voltage division and current division

Limitations of Ohm's Law:

- Not valid for non-linear elements (diodes, transistors)
- Not applicable at very high frequencies
- Not valid for non-metallic conductors like semiconductors
- Not applicable for vacuum tubes and gaseous devices

Mnemonic

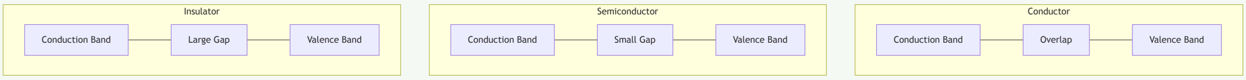
"Voltage Drives, Resistance Restricts"

Question 2(a) [3 marks]

Draw and explain energy band diagrams for insulator, conductor and Semiconductor.

Solution

Energy Band Diagrams:



- **Conductor**: Valence and conduction bands overlap, allowing easy electron flow
- **Semiconductor**: Small energy gap (~1eV) between bands; electrons can jump with thermal energy
- **Insulator**: Large energy gap (>5eV) prevents electron movement between bands

Mnemonic

"Conductors Connect, Semiconductors Sometimes, Insulators Impede"

Question 2(b) [4 marks]

Write statement of Maximum power transfer theorem and reciprocity theorem.

Solution

Theorem	Statement
Maximum Power Transfer Theorem	Maximum power is transferred from source to load when load resistance equals the source internal resistance (RL = RS)
Reciprocity Theorem	In a linear passive network with a single source, if the source is moved from position A to B, the current at A due to source at B will equal the current at B when source was at A

Diagram:

```
Maximum Power Transfer:
        +---[Source]---+
        |              |
        R(source)      R(load)
        |              |
        +------+-------+
```

Mnemonic

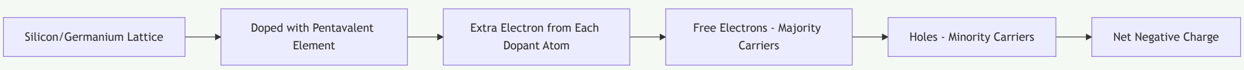
"Match Resistance to Maximize Power; Switch Source and Sink, Current Stays Same"

Question 2(c) [7 marks]

Explain the formation and conduction of N-type materials.

Solution

N-type Semiconductor Formation:



- **Doping Process**: Silicon/Germanium (4 valence e$^-$)$dopedwithpentavalentelements(P, As, Sb)$
- **Extra Electron**: Each dopant atom provides 1 extra electron after covalent bonding
- **Conduction Mechanism**:
  - **Majority Carriers**: Free electrons (negative charge carriers)
  - **Minority Carriers**: Holes (very few)
- **Electrical Properties**: Increased conductivity and negative charge carriers

Mnemonic

"Pentavalent Provides Plus one Electron, Negative-type"

Question 2(a) OR [3 marks]

Define valence band, conduction band and forbidden gap.

Solution

Term	Definition
Valence Band	The highest energy band filled with electrons, where electrons are bound to atoms
Conduction Band	The band above valence band where electrons move freely and contribute to electrical conduction
Forbidden Gap	The energy range between valence and conduction bands where no electron states exist

Diagram:

Mnemonic

"Valence Holds, Forbidden Blocks, Conduction Flows"

Question 2(b) OR [4 marks]

Define the terms active power, reactive power and power factor with power triangle.

Solution

Power Terms in AC Circuits:

Term	Definition
Active Power (P)	Actual power consumed, measured in watts (W); P = VI cos
Reactive Power (Q)	Power oscillating between source and load, measured in VAR; Q = VI sin
Power Factor (PF)	Ratio of active power to apparent power; PF = cos

Power Triangle:

```
                S (VA)
               /|
              / |
             /  |
            /   |
           /    |
         /_____|
        P(W)    Q(VAR)
```

- **Apparent Power (S)**: Vector sum of active and reactive power
- **Power Triangle**: Right triangle with P, Q, and S as sides
- **Power Factor**: cos = P/S (0 to 1)

Mnemonic

"Active Power Works, Reactive Power Waits"

Question 2(c) OR [7 marks]

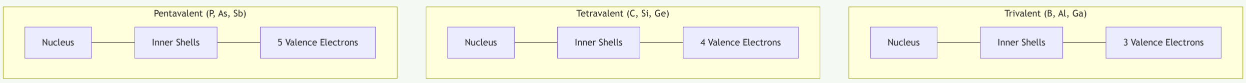
Explain the structure of atom of trivalent, tetravalent and pentavalent elements.

Solution

Atomic Structures:

Element Type	Valence Electrons	Examples	Electronic Configuration
Trivalent	3	Boron, Aluminum, Gallium	3 electrons in outermost shell
Tetravalent	4	Carbon, Silicon, Germanium	4 electrons in outermost shell
Pentavalent	5	Nitrogen, Phosphorus, Arsenic	5 electrons in outermost shell

Diagram:



- **Trivalent Elements**: Used as p-type dopants in semiconductors
- **Tetravalent Elements**: Form semiconductor base materials
- **Pentavalent Elements**: Used as n-type dopants in semiconductors

Mnemonic

"Three Tries to Bond, Four Forms Full bonds, Five Frees an Electron"

Question 3(a) [3 marks]

Draw the symbol of photodiode and state it's application.

Solution

Photodiode Symbol:

```
    --------|>|--------
             |
            / \
           /   \
```

Applications of Photodiode:

- Light sensors and detectors
- Optical communication systems
- Camera exposure controls
- Barcode scanners
- Medical instruments
- Solar cells

Mnemonic

"Photons Produce Current"

Question 3(b) [4 marks]

Write a Short note on LED.

Solution

LED (Light Emitting Diode):

Parameter	Description
Structure	p-n junction with special doping materials
Working	Electrons recombine with holes, releasing energy as photons
Materials	GaAs (red), GaP (green), GaN (blue), etc.
Voltage	Forward voltage typically 1.8V to 3.3V depending on color

Advantages:

- High efficiency (low power consumption)
- Long life (50,000+ hours)
- Small size and durability
- Various colors available

Applications:

- Indicators and displays
- Lighting systems
- TV/monitor backlights
- Traffic signals

Mnemonic

"Light Emits when Diode conducts"

Question 3(c) [7 marks]

Draw and explain VI characteristic of PN junction diode.

Solution

P-N Junction Diode V-I Characteristic:

```
                        |
                        |         /
                        |        /
                        |       /
                        |      /
                        |     /
                        |    /
-----------+------------+---+----------
           |            |  /|
           |            | / |
           |            |/  |
           |            |   |
           |            |   |
           +            +   +
       Reverse      Origin Forward
       Region              Region
```

Forward Bias Region:

- **Knee Voltage**: 0.3V (Ge), 0.7V (Si) where current starts flowing
- **Current Equation**: I = Is(e^(qV/kT) - 1)
- **Conductivity**: High (low resistance)

Reverse Bias Region:

- **Leakage Current**: Very small reverse current (micro-amps)
- **Breakdown Region**: Sharp increase in current at breakdown voltage

- **Conductivity**: Very low (high resistance)

Key Points:

- **Barrier Potential**: Decreases in forward bias, increases in reverse bias
- **Diode Resistance**: Dynamic resistance changes with applied voltage
- **Temperature Effect**: Voltage drop decreases with temperature increase

Mnemonic

"Forward Flows Freely, Reverse Resists"

Question 3(a) OR [3 marks]

List the applications of PN junction diode.

Solution

Applications of PN Junction Diode:

Application Category	Examples
Rectification	Half-wave rectifier, Full-wave rectifier, Bridge rectifier
Signal Processing	Signal demodulation, Clipping circuits, Clamping circuits
Protection	Voltage spike protection, Reverse polarity protection
Logic Gates	Diode logic circuits, Switching applications
Voltage Regulation	Zener diodes for voltage references
Light Applications	LEDs, Photodiodes, Solar cells

Mnemonic

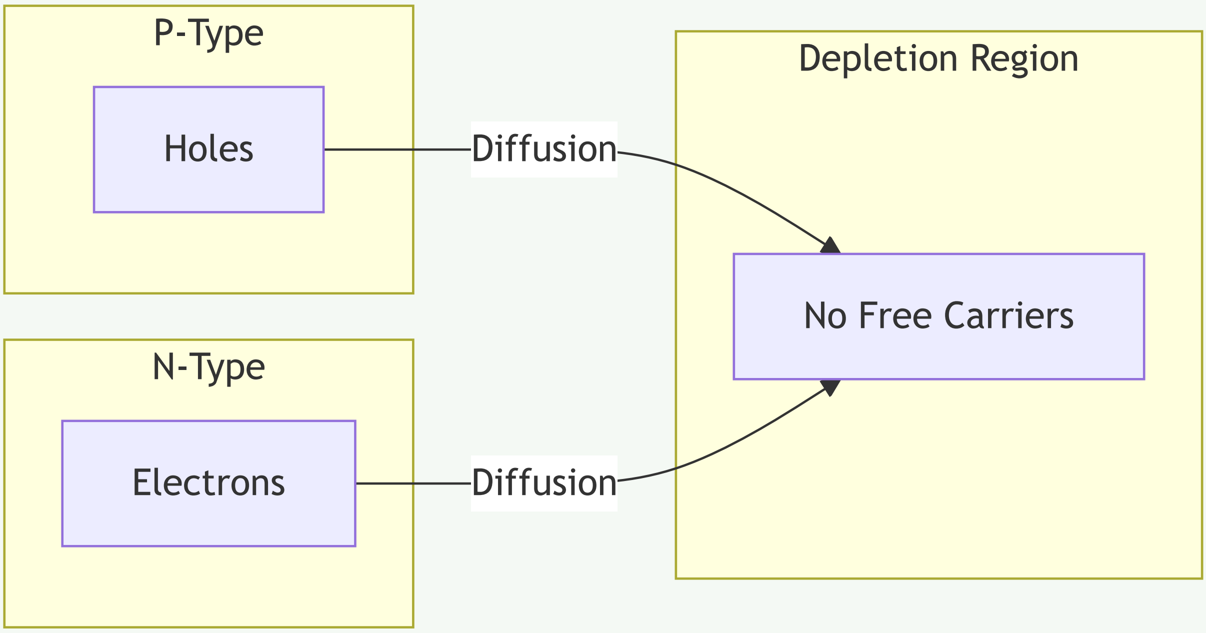
"Rectify, Process, Protect, Logic, Regulate, Light"

Question 3(b) OR [4 marks]

Explain the formation of depletion region in unbiased P-N junction.

Solution

Depletion Region Formation:



Process:

- **Diffusion**: Electrons from n-side diffuse to p-side; holes from p-side diffuse to n-side
- **Recombination**: Electrons and holes recombine at the junction
- **Immobile Ions**: Exposed positive ions in n-region, negative ions in p-region
- **Electric Field**: Forms between positive and negative ions, opposing further diffusion
- **Equilibrium**: Diffusion current equals drift current; no net current flows

Properties of Depletion Region:

- No free charge carriers
- Acts as insulator
- Width depends on doping levels
- Contains built-in potential barrier

Mnemonic

"Diffusion Depletes Carriers, Creating Electric barrier"

Question 3(c) OR [7 marks]

Explain construction, working and applications of PN junction diode.

Solution

Construction of PN Junction Diode:

```
    +---------+---------+
    |         |         |
    |  P-Type|N-Type   |
    |         |         |
    +---------+---------+
       |     |      |
       |Depletion|
       |  Region |
```

- **P-Type Region**: Silicon/Germanium doped with trivalent impurities (boron, aluminum)
- **N-Type Region**: Silicon/Germanium doped with pentavalent impurities (phosphorus, arsenic)
- **Junction**: Interface between p and n regions with depletion layer
- **Terminals**: Anode (p-side) and Cathode (n-side)

Working Principle:

Bias Condition	Behavior
Forward Bias	Depletion region narrows, current flows when V > 0.7V (Si)
Reverse Bias	Depletion region widens, only small leakage current flows

Applications:

- Rectification in power supplies
- Signal demodulation in radios
- Voltage regulation (Zener)
- Signal clipping and clamping
- Logic gates and switching
- Light emission and detection

Mnemonic

"Forward Flow, Reverse Restrict, Convert AC to DC"

Question 4(a) [3 marks]

Define: (1) Ripple frequency (2) Ripple factor (3) PIV of a diode.

Solution

Term	Definition
Ripple Frequency	The frequency of AC component present in rectified DC output; for half-wave f = supply frequency, for full-wave f = 2 $\times supply frequency$
Ripple Factor ( )	Ratio of RMS value of AC component to DC component in rectifier output; = Vac(rms)/Vdc
PIV of Diode	Peak Inverse Voltage - maximum reverse voltage a diode can withstand without breakdown

Mnemonic

"Ripples Per second, Ripple Proportion, Reverse Peak Voltage"

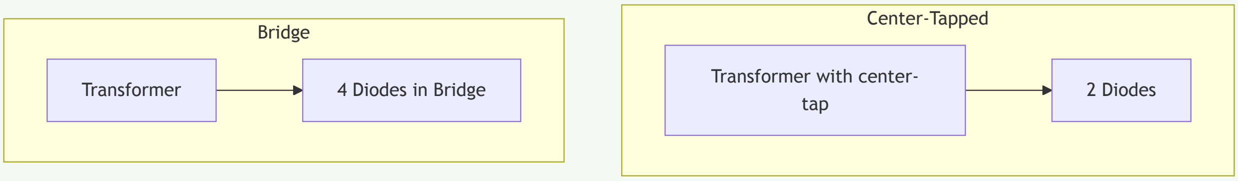
Question 4(b) [4 marks]

Give comparison between full wave rectifier with two diodes and full wave bridge rectifier.

Solution

Parameter	Center-Tapped Full Wave	Bridge Rectifier
Diodes Used	2 diodes	4 diodes
Transformer	Center-tapped required	No center tap needed
PIV of Diode	2Vm	Vm
Output Voltage	Vdc = 0.637Vm	Vdc = 0.637Vm
Ripple Factor	0.48	0.48
Efficiency	81.2%	81.2%
TUF	0.693	0.693

Diagram:



Mnemonic

"Bridge Beats Tap with Lower PIV but Needs More Diodes"

Question 4(c) [7 marks]

Explain zener diode as voltage regulator.

Solution

Zener Diode Voltage Regulator:

```
   Vin     Rs
   +------|\/\/\|------+--------+ Vout
   |                   |        |
   |                   Z        RL
   |                   Z Zener  |
   |                   Z        |
   +-------------------+--------+
                       |
                      GND
```

Working Principle:

- **Reverse Biased**: Zener operates in breakdown region
- **Constant Voltage**: Maintains fixed voltage (Vz) across its terminals
- **Current Regulation**: Series resistor (Rs) limits current
- **Load Changes**: When load current changes, Zener current changes to maintain constant output voltage

Design Equations:

- Rs = (Vin - Vz) / (IL + Iz)
- Power rating of Zener: Pz = Vz $\times Iz(max)$

Advantages:

- Simple circuit
- Low cost
- Good regulation for small loads
- Fast response to load changes

Limitations:

- Power wastage in Rs and Zener
- Limited output current capability
- Temperature dependence of Vz

Mnemonic

"Zener Stays at breakdown Voltage despite Current changes"

Question 4(a) OR [3 marks]

What is rectifier? Explain full wave rectifier with waveforms.

Solution

Rectifier: A circuit that converts AC voltage to pulsating DC voltage by allowing current flow in one direction only.

Full Wave Rectifier:

```
                    D1
   AC     +--------->|-------+
   Input  |                  |
   o------+                  +-----o
          |                  |     DC
          |                  |     Output
   o------+                  +-----o
          |                  |
          +--------|<--------+
                  D2
```

Waveforms:

```
Input:     ^     ^     ^
           |     |     |
   0 -----+-----+-----+----
           |     |     |
           v     v     v

Output:    ^     ^     ^
           |     |     |
   0 -----+-----+-----+----
```

- **Operation**: Both half cycles of AC input are converted to same polarity
- **Frequency**: Output ripple frequency is twice the input frequency
- **Voltage**: Vdc = 0.637Vm (where Vm is peak input voltage)

Mnemonic

"Full Wave Forms Full Output"

Question 4(b) OR [4 marks]

Why filter is required in rectifier? State the different types of filter and explain any one type of filter.

Solution

Need for Filters: Rectifiers produce pulsating DC with large ripples; filters smooth this output to provide steady DC voltage.

Types of Filters:

- Capacitor (C) filter
- Inductor (L) filter
- LC filter
- (Pi) filter
- RC filter

Capacitor Filter:

```
    +-------+-----+
    |       |     |
    |       C     RL
    |       |     |
    +-------+-----+
```

Working:

- Capacitor charges during voltage rise
- Discharges slowly through load during voltage fall
- Acts as temporary storage element
- Time constant RC determines discharge rate
- Reduces ripple by providing discharge path

Advantages:

- Simple and economical
- Good smoothing for light loads
- Increases DC output voltage

Mnemonic

"Capacitor Catches Charge and Releases Slowly"

Question 4(c) OR [7 marks]

Write the need of rectifier. Explain bridge rectifier with circuit diagram and draw its input and output waveforms.

Solution

Need for Rectifiers:

- Convert AC to DC for electronic devices
- Power supplies for DC-operated equipment
- Battery charging circuits
- DC power for industrial drives
- Signal demodulation in communication

Bridge Rectifier Circuit:

```
           D1       D3
     +----->|----+--|>----+
     |             |      |
AC   |             |      | DC
Input|             |      | Output
     |             |      |
     +------|<----+--|<---+
            D2       D4
```

Working Principle:

- **Positive Half Cycle**: D1 and D4 conduct, D2 and D3 block
- **Negative Half Cycle**: D2 and D3 conduct, D1 and D4 block
- **Both Half Cycles**: Current flows in same direction through load

Input-Output Waveforms:

```
Input:     ^      ^      ^
           |      |      |
    0 -----+------+------+-----
           |      |      |
           v      v      v

Output:    ^      ^      ^      ^      ^
           |      |      |      |      |
    0 ------+----+------+------+------+----
```

Characteristics:

- Vdc = 0.637Vm (Vm: peak input voltage)
- PIV of each diode = Vm
- Ripple factor = 0.48
- Efficiency = 81.2%
- TUF = 0.693

Mnemonic

"Bridge Brings Both halves to Direct Current"

Question 5(a) [3 marks]

Explain causes of electronic waste.

Solution

Causes of Electronic Waste:

Cause	Description
Rapid Technology Change	Frequent upgrades and obsolescence of electronics
Short Lifecycle	Devices designed with limited useful life
Consumer Behavior	Preference for new gadgets over repair
Manufacturing Issues	Poor quality leading to early failures
Economic Factors	Sometimes cheaper to replace than repair
Marketing Strategies	Promoting new models through planned obsolescence

Mnemonic

"Upgrade, Use, Throw, Repeat"

Question 5(b) [4 marks]

Compare PNP and NPN transistors.

Solution

Parameter	PNP Transistor	NPN Transistor
Symbol		
Current Flow	Emitter to Collector	Collector to Emitter
Majority Carriers	Holes	Electrons
Biasing	Emitter positive, Collector negative	Collector positive, Emitter negative
Switching Speed	Slower	Faster
Usage	Less common	More common

Mnemonic

"PNP: Positive to Negative to Positive; NPN: Negative to Positive to Negative"

Question 5(c) [7 marks]

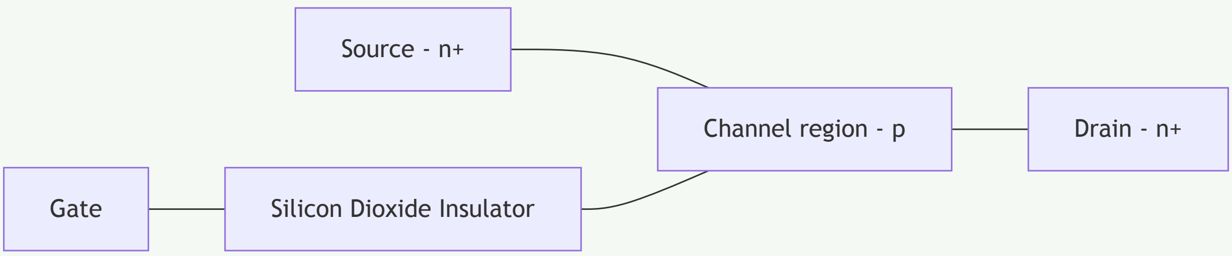
Draw the symbol, explain the construction and working of MOSFET.

Solution

MOSFET Symbol (N-Channel Enhancement):

```
       D
       |
       |
    G---|
       |
       |
       S
```

Construction:



Components:

- **Substrate**: P-type semiconductor body
- **Source/Drain**: Heavily doped n+ regions

- **Gate**: Metal electrode separated by insulator (SiO2)
- **Channel**: Forms between source and drain when biased

Working Principle:

- **Enhancement Mode**: No channel exists initially; gate voltage creates channel
- **Threshold Voltage (VT)**: Minimum gate voltage needed to form channel
- **Conducting State**: When VGS > VT, electrons form channel, allowing current flow
- **Saturation Region**: Current remains constant despite increase in VDS
- **Linear Region**: Current proportional to VDS at low drain voltages

Applications:

- Digital circuits (logic gates)
- Power amplifiers
- Switching applications
- Memory devices

Mnemonic

"Gate Voltage Controls Electron Channel"

Question 5(a) OR [3 marks]

Explain methods to handle electronic waste.

Solution

Methods to Handle Electronic Waste:

Method	Description
Reduce	Designing products with longer lifecycle and upgradability
Reuse	Refurbishing and donating electronics for secondary use
Recycle	Systematic disassembly to recover valuable materials
Responsible Disposal	Proper collection and processing by certified facilities
Extended Producer Responsibility	Manufacturers take back used products
Urban Mining	Recovering precious metals from discarded electronics

Diagram:

Mnemonic

"Reduce, Reuse, Recycle, Recover Resources"

Question 5(b) OR [4 marks]

Derive the relationship between dc and dc.

Solution

Relationship between and :

Given:

- dc = IC/IE (Common base current gain)
- dc = IC/IB (Common emitter current gain)

Derivation: From Kirchhoff's current law: IE = IC + IB

Dividing both sides by IC: IE/IC = 1 + IB/IC

Since dc = IC/IE: 1/ dc = 1 + IB/IC

Since dc = IC/IB: 1/ dc = 1 + 1/ dc

Final Relations:

- dc = dc/(1 + dc)

- dc = dc/(1 - dc)

Table: | **Value** | **Value** | |————-|————-| | 0.9 | 9 | | 0.95 | 19 | | 0.99 | 99 |

Mnemonic

"Alpha approaches One as Beta approaches Infinity"

Question 5(c) OR [7 marks]

Explain common collector configuration with its input and output characteristics.

Solution

Common Collector (Emitter Follower) Configuration:

```
                   +Vcc
                     |
                     |
                     R
                     |
                     |
    +------+--------+-------+
    |      |                |
    |    B |    C           E
    +-----|       |-------+-+
           |      |       |
         --+      +--     R
           |                |
           |                |
         +-+-+              |
         |   |              |
         GND GND            GND
```

Input Characteristics:

```
   Ib
   ^
   |      -------
   |     /
   |    /
   |   /
   |  /
   | /
   |/
   +-----------------> Vbe
```

Output Characteristics:

```
   Ie
   ^
   |       --------
   |      /
   |     /
   |    /
   |   /
   |  /
   | /
   |/
   +-----------------> Vce
```

Key Features:

- **Voltage Gain (Av)**: Approximately 1 (unity)
- **Current Gain (Ai)**: High (+ 1)
- **Input Impedance**: High ($\times RE$)
- **Output Impedance**: Low (1/gm) where gm is transconductance
- **Phase Relationship**: No phase inversion between input and output

- **Applications**: Impedance matching, buffers, voltage regulators

Characteristics:

- **Input Resistance**: Ri = $\times (re + RL)$
- **Output Resistance**: Ro = (rs + re)/(+ 1)
- **Voltage Gain**: Av = RL/(RL + re) ≈ 1
- **Current Gain**: Ai = (+ 1)

Advantages:

- Very high input impedance
- Low output impedance
- Good impedance matching properties
- No phase inversion

Limitations:

- No voltage gain (slightly less than 1)
- Used only for impedance matching

Mnemonic

"Collector Common, Current amplifies, Voltage follows"
This completes the full solutions for the Elements of Electrical & Electronics Engineering (1313202) Winter 2023 examination.