# Elements of Electrical & Electronics Engineering (1313202) - Winter 2023 Solution

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## 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.
**Mathematical Form**: $\sum V = 0$ or $V_1 + V_2 + V_3 + V_4 = 0$

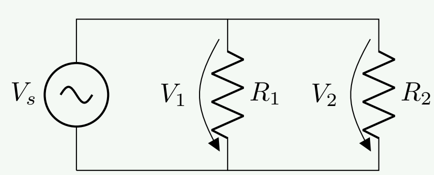



**Figure 1.** Closed Loop for KVL

- **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**: $I = V/R$

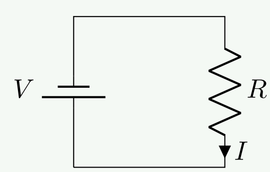



**Figure 2.** Ohm's Law Circuit

**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**:

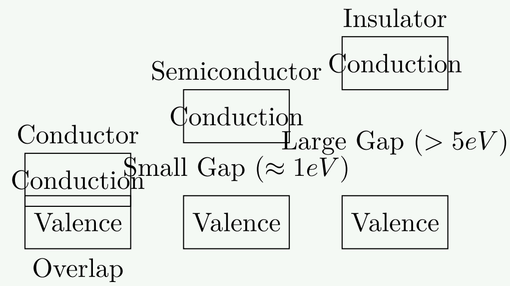



**Figure 3.** Energy Band Diagrams

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

**Mnemonic**

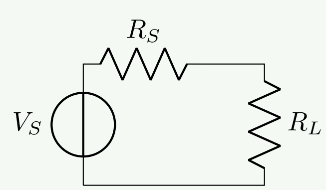
"Conductors Connect, Semiconductors Sometimes, Insulators Impede"

## 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 ($R_L = R_S$). |
| **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. |




Max Power when $R_L = R_S$

**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**:

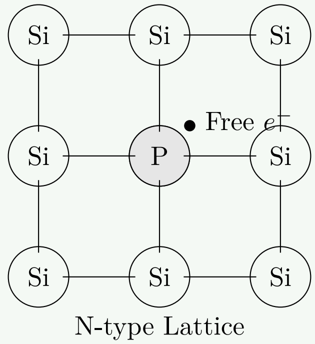



**Figure 4.** Pentavalent Doping (N-type)

- **Doping Process**: Silicon/Germanium (4 valence $e^-$) doped with pentavalent elements (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**

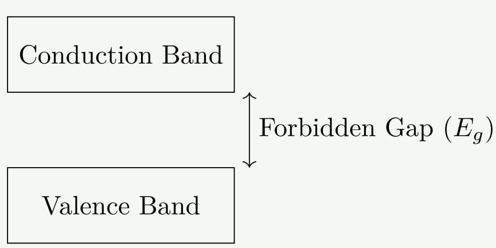
"Pentavalent Provides Plus one Electron, Negative-type"

## 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. |



**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); $P = VI\cos\theta$. |
| **Reactive Power (Q)** | Power oscillating between source and load, measured in VAR; $Q = VI\sin\theta$. |
| **Power Factor (PF)** | Ratio of active power to apparent power; $PF = \cos\theta$. |

**Power Triangle:**

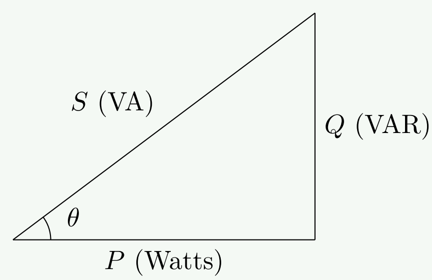



**Figure 5.** Power Triangle

- **Apparent Power (S)**: Vector sum of active and reactive power.
- **Power Factor**: $\cos\theta = P/S$ (0 to 1).

**Mnemonic**

"Active Power Works, Reactive Power Waits"

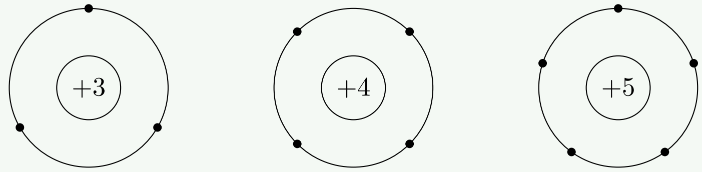
## Question 2(c) OR [7 marks]

### 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 |




Trivalent (3 $e^-$) Tetravalent (4 $e^-$) Pentavalent (5 $e^-$)

**Figure 6.** Valence Shell Electrons

- **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"

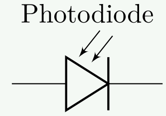
## Question 3(a) [3 marks]

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

**Solution**

**Photodiode Symbol:**

Photodiode



**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:**

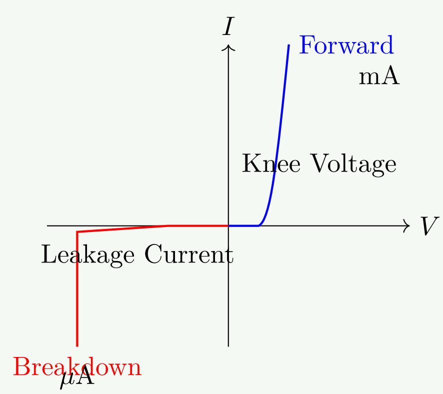



**Figure 7.** V-I Characteristics

**Forward Bias Region:**
- **Knee Voltage**: 0.3V (Ge), 0.7V (Si) where current starts flowing.
- **Current Equation**: $I = I_s(e^{qV/kT} - 1)$.
- **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:**

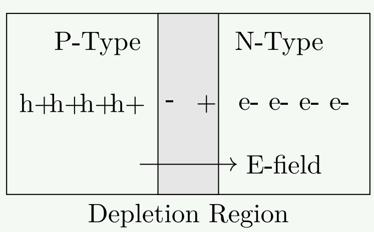



**Figure 8.** Depletion Region

**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:**

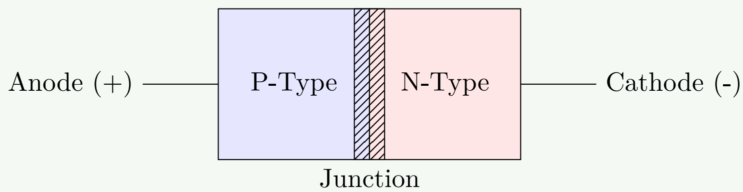



**Figure 9.** PN Junction Construction

- **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 $f = f_{in}$, for full-wave $f = 2f_{in}$. |
| **Ripple Factor ($\gamma$)** | Ratio of RMS value of AC component to DC component in rectifier output; $\gamma = V_{ac(rms)}/V_{dc}$. |
| **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** | $2V_m$ | $V_m$ |
| **Output Voltage** | $V_{dc} = 0.637V_m$ | $V_{dc} = 0.637V_m$ |
| **Ripple Factor** | 0.48 | 0.48 |
| **Efficiency** | 81.2% | 81.2% |
| **TUF** | 0.693 | 0.812 |

**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:**

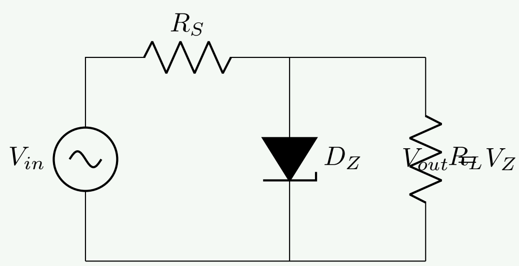



**Figure 10.** Zener Voltage Regulator

**Working Principle:**

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

**Design Equations:**

- $R_S = (V_{in} - V_Z)/(I_L + I_Z)$.
- Power rating of Zener: $P_Z = V_Z \times I_{Z(max)}$.

**Mnemonic**

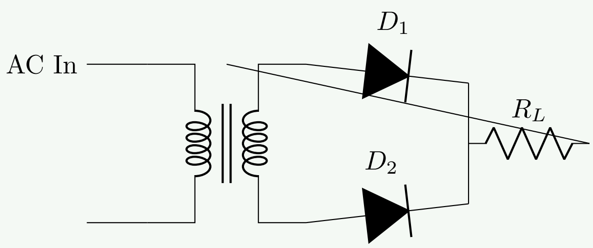
"Zener Stays at breakdown Voltage despite Current changes"

## 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 (Center-Tapped):**




**Waveforms:**

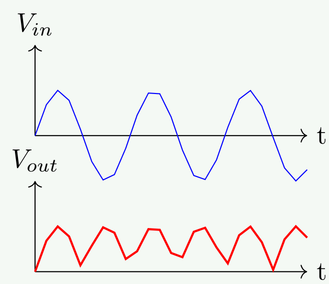



**Figure 11.** Full Wave Rectifier Waveforms

- **Operation**: Both half cycles of AC input are converted to same polarity.
- **Frequency**: Output ripple frequency is twice the input frequency.
- **Voltage**: $V_{dc} = 0.637V_m$.

**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.
- $\pi$ (Pi) filter.
- RC filter.

**Capacitor Filter:**

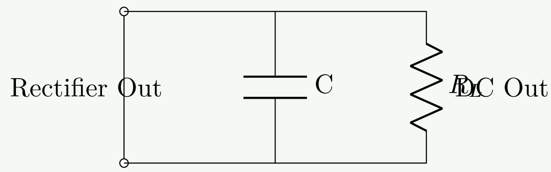



**Figure 12.** Capacitor Filter

**Working Principle:**
- Capacitor charges during voltage rise to peak.
- Discharges slowly through load during voltage fall.
- Reduces ripple by providing discharge path with time constant $RC$.

**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 and battery charging.
- Signal demodulation.

**Bridge Rectifier Circuit:**

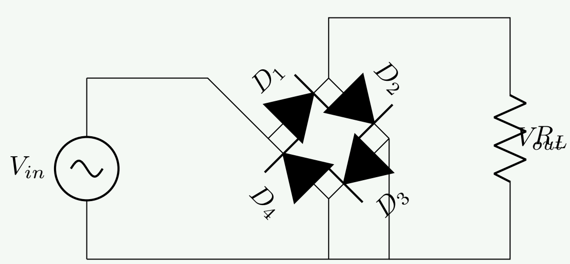



**Figure 13.** Bridge Rectifier

**Working Principle:**
- **Positive Half Cycle**: $D_1$ and $D_3$ conduct.
- **Negative Half Cycle**: $D_2$ and $D_4$ conduct.
- **Result**: Unidirectional current through $R_L$.

**Waveforms:** Input is sine wave, Output is pulsating DC (full-wave rectified).

**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. |
| **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 |
|---|---|---|
| **Majority Carriers** | Holes | Electrons |
| **Current Flow** | Emitter to Collector | Collector to Emitter |
| **Biasing** | Emitter +ve, Collector -ve | Collector +ve, Emitter -ve |
| **Switching Speed** | Slower | Faster |
| **Usage** | Less common | More common |

**Mnemonic**

"PNP: Positive-Negative-Positive; NPN: Negative-Positive-Negative"

## Question 5(c) [7 marks]

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

**Solution**

**MOSFET (N-Channel Enhancement):**

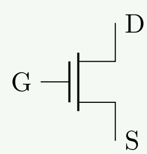



**Figure 14.** MOSFET Symbol

**Construction:**

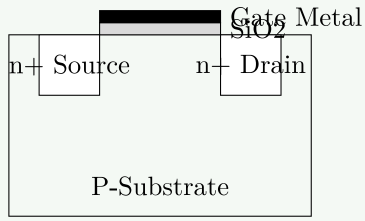



**Figure 15.** MOSFET Construction

**Working Principle (Enhancement Mode):**

- No channel exists initially.
- When positive voltage applied to Gate ($V_{GS} > V_{Th}$), electrons are attracted to surface.
- An N-channel is formed connecting Source and Drain, allowing current flow.

**Mnemonic**

"Gate Voltage Controls Electron Channel"

## Question 5(a) OR [3 marks]

**Explain methods to handle electronic waste.**

**Solution**

**Methods to Handle E-Waste:**

- **Reduce**: Designing long-lasting products.
- **Reuse**: Refurbishing used electronics.
- **Recycle**: Recovering materials.
- **Recover**: Extracting energy/metals.


**Mnemonic**

"Reduce, Reuse, Recycle, Recover Resources"

## Question 5(b) OR [4 marks]

**Derive the relationship between $\alpha_{dc}$ and $\beta_{dc}$.**

**Solution**

**Given:**

- $\alpha_{dc} = I_C/I_E$
- $\beta_{dc} = I_C/I_B$

**Derivation:** From KCL: $I_E = I_C + I_B$ Divide by $I_C$:

$$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$$

$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

$$\frac{1}{\alpha} = \frac{\beta + 1}{\beta}$$

$$\alpha = \frac{\beta}{1+\beta}$$

Similarly,

$$\beta = \frac{\alpha}{1-\alpha}$$

**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):**

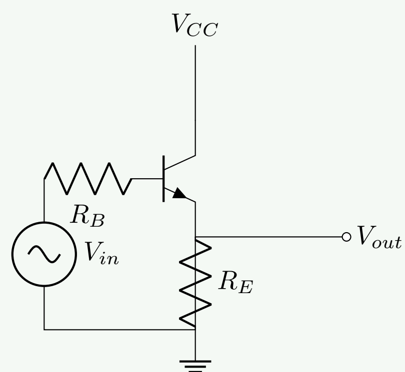



**Figure 16.** Common Collector Circuit

**Characteristics:**

- **Input**: Plot of $I_B$ vs $V_{BC}$. High input impedance.
- **Output**: Plot of $I_E$ vs $V_{CE}$. Low output impedance.
- **Voltage Gain**: $\approx 1$.
- **Current Gain**: High $(\beta + 1)$.

**Mnemonic**

"Collector Common, Current amplifies, Voltage follows"