CHAPTER 18

ELECTRONICS

Definition: “It is that branch of physics which deals with the emission, behaviour and effects of electrons (as in electron tubes and transistors) and with designing electronic devices such as diodes, Ics, microchips and microprocessors etc.”

P-n JUNCTION: “The interface between two regions in a semiconductor crystal which have been grown in such a way that its one part is p-type semiconductor and the other is n-type semiconductor, is known as p-n junction.”

Explanation:
A p-n junction is formed when a crystal of germanium or silicon is grown in such a way that its one-half is doped with a trivalent impurity and the other half with a pentavalent impurity. In p-n junction, n-region contains free electrons as majority charge carriers and p-region contains holes as majority charge carriers.

Just after the formation of the junction, the free electrons from n-region diffuse into the p-region and holes from p-region diffuse into the n-region. As a result of this diffusion, a charge.
less region is formed around the junction in which charge carriers are not present. This region is known as depletion region, as shown in fig. 1(a, b). In this fig. black dots (with arrows) represent the free electrons and the small circles show the holes whereas the circles with + and − signs show the positive and negative ions which constitute the depletion region. Due to these ions, a potential difference develops across the depletion region (fig. 1(b)). Its value is 0.7 V in case of silicon and 0.3 V in case of germanium. This P.D., called potential barrier, stops further diffusion of electrons and holes.

**Forward Biased p-n Junction:**

When a battery is connected across a p-n junction with its positive terminal to the p-type side and its negative terminal to the n-type side, then due to this external potential difference, energy is supplied to the free electrons in the n-region and to holes in the p-region. Due to this, the depletion region becomes narrow. When this energy is sufficient to overcome
the potential barrier, a current of the order of a few milliamperes begins to flow across the p-n junction. In this state the p-n junction is said to be forward biased (fig-2(a)).

The variation of current through the junction with the bias voltage can be studied by the circuit as shown in fig-2(b).

The value of current for different values of bias voltage is noted and a "current-bias voltage" graph is plotted as shown in fig-3. It is also known as semi-conductor diode characteristic curve for forward bias.

If forward bias voltage is increased by \( \Delta V_f \), the current increases by \( \Delta I_f \). The ratio \( \frac{\Delta V_f}{\Delta I_f} \) is known as forward resistance of the p-n junction i.e., \( R_f = \frac{\Delta V_f}{\Delta I_f} \) (4)

![Graph showing current-bias voltage relationship](image)
Forward Resistance: "It is the resistance offered by the p-n junction when it is conducting. The value of 'R' is only a few ohms.

Reverse Biased p-n Junction:

When a battery is connected across a p-n junction with its positive terminal connected to the n-type side and its negative terminal to the p-type side, the p-n junction is said to be reverse biased, as shown in fig.-4(a).

In this case, the electrons and holes are repelled away from the junction and the depletion region becomes wide. Hence no current flows due to majority charge carriers. However, a very small current, of the order of few microamperes, flows across the junction due to flow of minority charge carriers. It is known as reverse current or leakage current. The variation of reverse current with the applied bias voltage can be studied by the circuit as shown in fig.-4(b).

Fig.-4 (c) shows the reverse characteristic for the p-n junction.
It can be seen that as the reverse voltage is increased from 0, the reverse current quickly rises to its saturation value $I_s$. As the reverse voltage is further increased, the reverse current remains almost constant. Here the resistance offered by the p-n junction is very high - of the order of several mega-ohms.

As the reverse voltage is increased, the K.E. of the minority charge carriers with which they cross the depletion region also increases till it is sufficient to break a covalent bond. As the covalent bond breaks, more electron-hole pairs are created. Thus, minority charge carriers begin to multiply due to which the reverse current begins to increase till a point is reached when the junction breaks down and reverse current rise sharply as shown in fig-4(c).

**Breakdown Voltage**: "The voltage at which the reverse current in the p-n junction rises sharply is called breakdown voltage".

After breakdown, the reverse current will rise to very high value which will damage the junction.

**Semi-conductor Diode**: "p-n junction is also known as a semi-conductor diode" whose symbolic representation is given in fig.5. The arrow-head...
represents the p-region and
known as anode (A). The vertical
line represents the n-region
and is known as cathode (C). The current flows
in the direction of arrow when the diode is
forward biased.

RECTIFICATION:

Definition: "The process of converting alternating
current into direct current is called rectification."

Types of Rectification: There are two types
of rectification:
(i) Half-wave rectification
(ii) Full-wave rectification

(i) Half-Wave Rectification: "The rectification
in which the current flows only during alternate
half cycles is known as half-wave rectification."
The circuit diagram for a half-wave rectifier
is shown in fig. 6(b), where an alternating voltage
of period \( T \), called
input voltage, is applied
to a diode 'D' which
is connected in series
with a load resistance
'R'. In this method only one-
half of alternating current
cycle is converted into direct current.

During the positive half cycle of the input alternating voltage i.e., during the interval \(0 \rightarrow T\), the diode 'D' is forward biased, so it offers a very low resistance and current flows through 'R'. The flow of current through 'R' causes a potential drop across it which varies in accordance with the alternating input as shown in fig-6(b).

During the negative half cycle i.e., during the period \(T \rightarrow \frac{T}{2}\), the diode is reverse biased. Now it offers a very high resistance, so practically no current flows through 'R' and potential drop across it is almost zero. The same events repeat during the next cycle and so on. The current through 'R' flows in only one direction which means it is direct current. However, this current flows in pulses as shown in fig-6(b). The voltage which appears across load resistance 'R' is known as output voltage.

(ii) **Full-Wave Rectification:** "The rectification in which output current flows in the same direction during both half cycles of the alternating input voltage is known as full-wave rectification."
A full-wave rectifier is shown in fig. 7.

**Fig. 7(a):** "In +ve half cycle"  
**Fig. 7(b):** "In -ve half cycle".

It consists of four diodes connected in a bridge type arrangement. That is why it is also called a bridge rectifier. We can understand the operation of this circuit by remembering that a diode conducts only when it is forward biased. During the positive half cycle, i.e., during the time interval \('0 \rightarrow T_b'\), the terminal \('A'\) of the bridge is +ve with respect to its other terminal \('B'\). Now the diodes \('D_2'\) and \('D_3'\) become forward biased and conduct. A current flows through the circuit in the direction shown by arrows in fig. 7(a).

During the negative half cycle, i.e., during the time interval \('T_b \rightarrow T'\), the terminal \('A'\) is -ve and \('B'\) is +ve. Now the diodes \('D_2'\) and \('D_3'\) conduct and current flows through the circuit in the direction shown by arrows in fig. 7(b).

By comparing fig. 7(a) and 7(b), it can be seen
that the direction of current flow through the load resistance ‘R’ is the same in both the halves of the cycle. Thus both halves of the alternating input voltage send a unidirectional current through ‘R’. The input and output voltages are shown in fig. 8. However, the output voltage is not smooth but pulsating. It can be made smooth by using a circuit known as filter.

* Full wave rectification can also be achieved using two diodes and a centre-tap transformer.

**SPECIALY DESIGNED P-N JUNCTIONS**

In addition to the use of semi-conductor diode as rectifiers, many types of p-n junctions have been developed for special purposes. Three most commonly used such diodes are:

(i) **Light Emitting Diode (LED)**

(ii) **Photo diode**

(iii) **Photo voltaic cell**

**Light Emitting Diode**: Light emitting diodes (LED’s) are made from special semi-conductor materials such as “gallium arsenide” and “gallium arsenide phosphide” in which the potential barrier between ‘p’ and ‘n’ sides is such that when an electron combines
with a hole during **forward bias** conduction, a photon of visible light is emitted. These diodes are commonly used as small light sources e.g., light indicators in T.V. and computers, in optical fibre transmitters etc., etc. A specially formed array of seven LED’s is used for displaying digits in electronic appliances such as calculators, digital watches and other measuring instruments as shown in fig. 9.

![Symbol](image)

**LED**

![A seven segment display](image)

Fig. 9: →

![Display](image)

**etc.**

**iii) Photo Diode:**

“A photodiode is a normal p-n junction used for the detection of light.”

It consists of a transparent window through which light can enter. It is operated in reverse biased condition as shown in fig. 10(a). A photodiode symbol is shown in fig. 10(b).

When no light is incident on the junction, the reverse current ‘I’ is almost negligible but if its p-n junction is exposed to light,
the reverse current increases with the intensity of light, as shown in fig-10(c).

A photodiode can turn its current **ON** and **OFF** in nanoseconds. Hence it is one of the fastest photo detection devices. **Fig.-10 (c).**

**Applications of photodiode:** It is used for:

(i) Detection of light—both visible and invisible.
(ii) Automatic switching
(iii) Logic circuits
(iv) Optical communication equipment
(v) Fast counters etc.

(iii) **Photovoltaic cell:**

"A p-n junction which converts light energy into electrical energy is called photovoltaic cell." It is commonly known as "Solar cell." **Fig.-11. A Photovoltaic cell.**

These are p-n junctions in which potential barrier between 'p' and 'n' regions is used to drive a current through external circuit when light is incident on junction as shown in **fig.-11.**

The current is directly proportional to the intensity of light. A single silicon photovoltaic cell produces
a small voltage of 0.6V and a current of few milliamperes.

In order to obtain greater power, series and parallel arrays of thousands of such cells are used. They are called photovoltaic panels and are commonly used in satellites and space stations to convert solar energy into electrical power needed to operate electronic devices on board.

**TRANSISTORS**:

1. **Introduction**: The word ‘Transistor’ is derived from “Transfer Resistor”. It is a multi-electrode semiconductor device that amplifies an electrical signal when transferred through it from its input terminal to output terminal. It was firstly invented by ‘John Bardeen’ in 1948.

2. **Definition**: “A Transistor consists of a single crystal of germanium or silicon which is grown in such a way that it has three regions.”

3. **Types**: There are two types of transistors:

   a. **n-p-n Transistor**:
   
   A transistor in which p-type material is sandwiched between two n-type materials is known as n-p-n transistor as shown in fig-12 (a).
(ii) **p-n-p transistor:**

A transistor in which n-type material is sandwiched between two p-type materials is known as p-n-p transistor as shown in fig. - 12(b).

* The direction of arrow in both type symbols is in the direction of hole flow (conventional current).

(4) **Construction:** In both types of transistors, the central region is known as base and the other two regions are called emitter and collector as shown in symbols above. Usually the base is very thin, of the order of \(10^{-6}\) m. The emitter and collector have greater concentration of impurity. The collector is comparatively larger than the emitter. The emitter have greater concentration of impurity as compared to the collector. It can be seen in figs. - 12(a) and 12(b) that a transistor is a combination of two back to back p-n junctions; emitter-base junction and collector-base junction.

(5) **Operation:** For normal operation of the transistor, two batteries \(V_{bb}\) and \(V_e\) are connected in such a way that its emitter-base junction is forward biased and its collector-base junction is reverse biased. The battery \(V_e\) is of much higher value than \(V_{bb}\).
The biasing arrangement for both types of transistors is shown in Fig. 13(a) and 13(b) respectively.

Fig. 13(a) Biasing in n-p-n.  
Fig. 13(b) Biasing in p-n-p.

It may be noted that polarities of the biasing batteries, \( V_{bb} \) and \( V_{cc} \), are opposite in the two types of the transistors. In actual practice, it is the n-p-n transistor that is generally used. So we will discuss n-p-n transistors only.

**Current flow in an n-p-n Transistor:**

In an n-p-n transistor the current flow is shown in Fig. 14. Fig. 14(a) shows a biased n-p-n transistor. Since the emitter-base junction is forward biased, the emitter injects a large number of electrons in the base region as shown in Fig. 14(b). These free electrons in the base can flow in either of the...
two directions. They can either flow out of the base to the positive terminal of "$V_{BB}$" or they can be attracted towards the collector because of greater battery "$V_{cc}$". Since the base is extremely thin, very few electrons manage to recombine with holes and escape out of the base. Almost all of the free electrons injected from the emitter into the base are attracted into the collector by the large positive of "$V_{cc}$" as shown in fig.-14(c). Thus, in a normally biased transistor due to above mentioned flow of electrons, we can say, that an electronic current "$I_e$" flows from emitter into the base. A very small part of it, current "$I_B$", flows out of the base, the rest current "$I_C$" (max. current), flows out of the collector as shown in fig.-15.

The flow of Conventional current is shown in fig.-16. In future we will use conventional current only. From fig.-16, it can be seen that:

$$I_E = I_C + I_B \quad (1)$$

As very few electrons flow out of base, so "$I_B$" is very small as compared to "$I_C$".

![Fig-15. Flow of electronic current in an npn transistor.](image)

![Fig-16. Flow of Conventional current in an npn transistor.](image)
It is also found that for a given transistor, the ratio of collector current \( I_c \) to base current \( I_b \) is nearly constant i.e., 
\[
\beta = \frac{I_c}{I_b} \rightarrow (2)
\]
The ratio \( \beta \) is called current gain of transistor. Its value is quite large - of the order of hundreds.

The equations (1) and (2) are fundamental equations of all transistors.

**Advantages:** The advantages of transistors are:
- Small size, light weight, low cost, longer life.
- No warm-up time (converse to electron-tubes).

**Disadvantages:** Low current handling, highly sensitive for temperature.

**Example 18.1:** In a certain circuit, the transistor has a collector current of 10mA and a base current of 40µA. What is the current gain of the transistor?

**Solution:** As given, \( I_c = 10 \text{ mA} = 10 \times 10^{-3} \text{ A}, \)
\( I_B = 40 \text{ µA} = 40 \times 10^{-6} \text{ A}. \)

\[
\beta = \frac{I_c}{I_B} = \frac{10 \times 10^{-3}}{40 \times 10^{-6}} = 250 , \quad \therefore \beta = 250.
\]

**TRANSISTOR AS AN AMPLIFIER**

**Definition:** “An amplifier is a device for reproducing an electrical input signal of small value into an output signal of large value.” Often it is a small alternating voltage that has to be amplified.
(2) **Transistor as an amplifier**:- In majority of electronic circuits, transistors are basically used as amplifiers. An amplifier is thus the building block of every complex electronic circuit. That is why the study of transistor amplifier is important.

(3) **Circuit Diagram**:-

An n-p-n transistor in common-emitter mode can act as a voltage amplifier with a suitable load resistance as shown in fig. 17. Fig. 17. N CE Amplifier

(4) **Construction**:- It has base-emitter as input terminals and collector-emitter as output terminals. The base battery \( V_{bb} \) forward biases the base-emitter junction and collector battery \( V_{cc} \) reverse biases the collector-base junction. Usually \( V_{cc} \) is much larger than \( V_{bb} \) i.e. \( V_{cc} \gg V_{bb} \).

(5) **Working**:- When a small alternating input voltage \( V_{in} \) (e.g. from a microphone) is applied across resistor \( R_b \), it adds a small alternating current \( I_{in} \) into the base current \( I_b \). This small alternating current is amplified by transistor \( \beta \)-times, so that an alternating current \( I_{out} \) is added in collector resistance \( R_c \) (also known as load resistance). This load resistance \( R_c \) converts these current changes into voltage changes.
which form the alternating output voltage $v_{out}$ being much greater than $V_{in}$.

Hence $I_{in}$ is the change in base current i.e., $\Delta I_B = I_{in}$.

Similarly $I_{out}$ is the change in collector current i.e., $\Delta I_C = I_{out}$. Now from fig.-17, $I_{in}$ can be found out keeping in view that $R_B \gg r_{ie}$. Thus:

$$I_{in} = \frac{V_{in}}{r_{ie}}$$

and

$$I_{out} = \frac{V_{out}}{R_C}$$

where $r_{ie}$ is the small internal resistance between its base and emitter terminal.

We know that:

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{I_{out}}{I_{in}} = \frac{V_{out}}{V_{in}} \cdot \frac{R_C}{r_{ie}}$$

or

$$\beta = \frac{V_{out}}{V_{in}} \cdot \frac{R_C}{r_{ie}}$$

which gives:

$$V_{out} = \beta \frac{R_C}{r_{ie}} V_{in} \quad \text{(A)}$$

The ratio $\frac{V_{out}}{V_{in}}$ is called **Voltage gain** of the amplifier. Therefore:

$$\text{Voltage gain} = \frac{V_{out}}{V_{in}} = \beta \frac{R_C}{r_{ie}}$$

For a typical arrangement: $R_C = 10 \, \text{k}\Omega$, $r_{ie} = 1 \, \text{k}\Omega$,

if $\beta = 50$, then:

$$\frac{V_{out}}{V_{in}} = 50 \times \frac{10 \, \text{k}\Omega}{1 \, \text{k}\Omega} = 500$$

which shows that output voltage is 500 times greater than the input voltage.

**TRANSISTOR SWITCH**

Transistors are used as switches in many important electronic circuits. The basic circuit in which transistor is used as a switch is shown in fig.-18. The collector $C$ and emitter $E$ behave as the terminals of the switch.
The circuit in which the current is to be turned **OFF** and **ON**, is connected across these terminals.

The base **B** and emitter **E** act as control terminals which decide the state of the switch.

**To turn the switch ON:**

In order to turn on the switch, a large potential difference $V_B$ is applied between control terminals **B-E** as shown in fig.-18(a). This injects a large current $I_B$ into the base circuit due to which a very heavy current $I_C$ begins to flow in the **C-E** circuit. This large value of collector current is possible only when the resistance between **C** and **E** drops down to such a small value that the potential drop across **CE** is nearly 0.1 volt.

As shown in fig.-18(a) emitter is at ground, so we can assume that collector is also at ground and collector-emitter circuit of fig.-18(c) can be drawn as shown in fig.-18(d). **CE** switch is closed and the bulb glows due to flow of large collector current.
To turn the switch OFF:  In order to turn the switch off, the base current \( I_B \) is set zero by opening the base circuit as shown in Fig. 18(c). As \( I_c = \beta I_B \), so \( I_c \) becomes zero and the \( C-E \) circuit becomes open as shown in Fig. 18(d). Now the resistance between \( C \) and \( E \) becomes nearly infinity which opens the \( CE \) switch.

Advantages of Transistor switching:

The transistor switching occurs electronically i.e. not to be done manually. It may be done by taking the input from another circuit. Also, it can occur in a time of one millionth of a second.

As an example, an electronic computer is basically a vast arrangement of electronic switches which are made from transistors.

**OPERATIONAL AMPLIFIER**

(1) Definition: “An operational amplifier (op-amp) is an electronic circuit that can perform electronically, mathematical operations such as addition, multiplication and division etc.”

Firstly op-amps were made from discrete (separate) components, but these are now available in integrated circuit (IC) form. These amplifiers belong to the linear (analogue) group, yet they can perform non-linear (digital) operations.
(2) Construction - Since an amplifier is an important electronic circuit that is used in almost every electronic instrument, so instead of making amplifier circuit by discrete components, the whole amplifier is integrated on a small silicon chip and enclosed in a capsule. Pins connected with working terminals such as input, output and power supply project outside the capsule as shown in Fig. 19(a). The enclosed circuit of the amplifier is used by making required connections with these pins. Such an integrated amplifier is known as operational amplifier, as symbolically shown in Fig. 19(b). Fig. 19 An op-amp.

It has two input terminals, one is known as inverting input (-) and the other non-inverting input (+). A signal that is applied at the inverting (-) input, appears after amplification, at the output terminal with a phase shift of 180° as shown in Fig. 20(a).

It can be seen that the signal is inverted as it appears at the output. That is why this terminal is known as inverting. If the signal is applied at non-inverting
Input (+), it is amplified at the output without any change of phase as shown in fig. 20(b).

**Characteristics of Op-amp:**

An op-amp has a large no. of characteristic parameters. We will discuss here only three of them:

(i) **Input Resistance:**

It is the resistance between the (+) and (-) inputs of the amplifier as shown in fig. 21(a). Its value is very high, of the order of several mega ohms. Due to high value of the input resistance $R_{in}$, practically no current flows between the two input terminals. It is a very important feature of op-amps.

(ii) **Output Resistance:**

It is the resistance between the output terminal and ground as shown in fig. 21(b). Its value is only a few ohms. It is denoted by $R_{o}$.

(iii) **Open Loop Gain:**

It is the ratio of output voltage $V_{o}$ to the voltage difference between non-inverting and inverting inputs when there is no external connection between the output and inputs as shown in fig. 21(c). It is denoted...
**OP-AMP AS INVERTING AMPLIFIER:**

The circuit diagram of an op-amp when used as an inverting amplifier is shown in Fig. 22. The input signal $V_i$, which is to be amplified, is applied at inverting terminal (-) through resistance $R_1$. $V_o$ is its output. The non-inverting terminal (+) is grounded, i.e., its potential is zero. We know that $A_{ol}$ is very high, of the order of $10^5$, so for any value of $V_i$, $V_+ - V_0 \approx 0$ or $V_0 \approx V_+$. Since $V_+$ is at ground so $V_0$ is virtually at ground potential i.e., $V_0 \approx 0$. From fig. 22 we can write:

**Current through $R_1$:**

$$I_1 = \frac{V_i - V_0}{R_1} = \frac{V_i - 0}{R_1} = \frac{V_i}{R_1} \quad \text{(A)}$$

or

$$I_1 = \frac{V_i}{R_1} \quad \text{(A)} \quad \text{(: } V_0 \approx 0)$$

Similarly:

**Current through $R_2$:**

$$I_2 = \frac{V_+ - V_o}{R_2} = \frac{0 - V_o}{R_2} \quad \text{(B)}$$

As practically no current flows between (-) and (+) terminals, so according to Kirchhoff's current rule:

$$I_1 = I_2 \quad \text{i.e.,} \quad \frac{V_i}{R_1} = -\frac{V_o}{R_2} \quad \text{or} \quad \frac{V_o}{V_i} = -\frac{R_2}{R_1} \quad \text{(C)}$$

As $\frac{V_o}{V_i}$ is defined as voltage gain $G$ of the inverting amplifier, so:

$$G = -\frac{R_2}{R_1} \quad \text{(C)}$$

The '$-V_o$' sign in eq. (3) indicates that the output
Signal is 180° out of phase with respect to input signal. For example: If $R_1 = 10 \text{k}\Omega$, $R_2 = 100 \text{k}\Omega$, the gain of the amplifier is: 

$$G = -\frac{R_2}{R_1} = -\frac{100 \text{k}\Omega}{10 \text{k}\Omega} = -10$$

* The gain of amplifiers depends only on $R_1, R_2$. 

**OP-AMP AS NON-INVERTING AMPLIFIER:**

The circuit diagram of an op-amp as non-inverting amplifier is shown in fig. 23. In this case, the input signal $V_i$ is applied at the non-inverting terminal (+). Due to high open loop gain of amplifiers, the inverting (-) and non-inverting (+) inputs are virtually at the same potential i.e., $V_+ = V_0 = V_i$. So from fig. 23, we can write:

$$I_1 = -\frac{V_i}{R_1} \quad \text{(A)}$$

Similarly, current through $R_2$ is:

$$I_2 = \frac{V_i - V_0}{R_2} \quad \text{(B)}$$

As practically no current flows between (-) and (+) terminals, so by Kirchhoff's current rule: $I_1 = I_2$

$$-\frac{V_i}{R_1} = \frac{V_i - V_0}{R_2}$$

Hence:

$$\frac{V_0}{R_2} = \frac{V_i}{R_2} - \frac{V_i}{R_1}$$

or:

$$\frac{V_0}{R_2} = \frac{1}{R_1} + \frac{1}{R_2} = V_i \left( \frac{1}{R_1} + \frac{1}{R_2} \right)$$

or:

$$\frac{V_0}{V_i} = \frac{R_2}{R_1} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) = \frac{R_2}{R_1} + 1$$

* Gain $= \frac{V_0}{V_i} = 1 + \frac{R_2}{R_1}$.\)
The above result shows that the ‘gain’ of amplifier depends upon the two externally connected resistances $R_1, R_2$, and is independent of its internal structure.

The positive sign of gain indicates that the input and output signals are in phase.

**Example 18.2:** Find the gain of the circuit as shown in fig. 24.

**SOL.:** As the input signal is applied at (+), so the op-amp acts as non-inverting amplifier. Comparing fig. 24 with fig. 23, we have:

$$R_1 = \infty, \quad R_2 = 0, \quad \text{Gain} = 1 + \frac{R_2}{R_1}$$

$$\therefore \text{Gain} = 1.$$

**OP-AMP AS A COMPARATOR**

“A circuit which can be used to compare the ‘voltages’ is called comparator.”

Op-amp usually requires two power supplies of equal voltages but of opposite polarity. Most op-amps operate with $V_c = \pm 12V$ as shown in fig. 25(a).

As the open loop gain of the op-amp is very high (10^6), therefore, even a very small potential difference between the inverting and non-inverting inputs is amplified to such a large
The amplifier gets saturated, i.e., its output either becomes equal to $V_\text{cc}$ or $-V_\text{cc}$. This feature of an op-amp is used to compare two voltages—hence the name comparator. The circuit of an op-amp used as a comparator is shown in Fig. 25(b). Here $V_0$ is reference voltage which is connected with (+) terminal and $V'$ is the voltage which is to be compared with the reference voltage $V_R$. It is connected with (-) terminal.

When $V > V_0$ or $V > V_R$, then $V_0 = -V_\text{cc}$
and if $V < V_0$ or $V < V_R$, then $V_0 = +V_\text{cc}$.

**Comparator as a Night Switch:**

As an application of a comparator circuit, suppose it is required that when the intensity of light falls below a certain level, the street light is automatically switched on. This can be made possible by using an op-amp as a comparator as shown in Fig. 26. Here $R_1$ and $R_2$ resistances form a potential divider. The potential drop across $R_2$ provides the reference voltage $V_R$ to the (+) input of the op-amp. Solving the potential divider for $V_R$ we have:

$$I_1 = \frac{V_\text{cc} - V_R}{R_1} \quad \text{and} \quad I_2 = \frac{V_R}{R_2}$$

Using Kirchhoff's current rule: $I_1 = I_2$

$$\therefore \quad \frac{V_\text{cc} - V_R}{R_1} = \frac{V_R}{R_2} \quad \text{or} \quad \frac{V_\text{cc}}{R_1} - \frac{V_R}{R_1} = \frac{V_R}{R_2}$$
or, \[ \frac{V_{cc}}{R_1} = \frac{V_R}{R_1} + \frac{V_R}{R_2} = V_R \left( \frac{1}{R_1} + \frac{1}{R_2} \right) = V_R \left( \frac{R_1 + R_2}{R_1 R_2} \right) \]

or, \[ \frac{V_{cc}}{R_1} = V_R \left( \frac{R_1 + R_2}{R_1 R_2} \right) \quad \Rightarrow \quad V_R = \frac{V_{cc}}{R_1} \times \left( \frac{R_2}{R_1 + R_2} \right) \]

\[ \therefore \quad V_R = \left( \frac{R_2}{R_1 + R_2} \right) V_{cc} \quad \rightarrow (A) \]

LDR is a light dependent resistance. The value of its resistance \( R_L \) depends upon the intensity of light falling upon it. The resistance \( R_L \) and \( R_o \) form another potential divider. The potential drop across \( R_o \) is \( V_o = V \) which can be found by solving the potential divider for \( V \) as follows:

\[ I = \frac{V_{cc} - V_o}{R_L} = \frac{V_{cc} - V}{R_L} \]

and:

\[ I = \frac{V_o}{R_o} = \frac{V}{R_o} \quad (\therefore \ V_o = V) \]

\[ \therefore \quad \frac{V_{cc} - V}{R_L} = \frac{V}{R_o} \quad \text{or} \quad \frac{V_{cc}}{R_L} - \frac{V}{R_o} = \frac{V}{R_o} \]

\[ \therefore \quad \frac{V_{cc}}{R_L} = \frac{V}{R_o} + \frac{V}{R_L} = \frac{V}{R_o} \times \left( \frac{R_o + R_L}{R_o R_L} \right) \]

\[ \therefore \quad \frac{V_{cc}}{R_L} = \frac{V}{R_o} \times \left( \frac{R_o + R_L}{R_o R_L} \right) \quad \Rightarrow \quad V = \frac{V_{cc}}{R_L} \times \left( \frac{R_o R_L}{R_o + R_L} \right) \]

\[ \therefore \quad V = \left( \frac{R_o}{R_o + R_L} \right) V_{cc} \quad \rightarrow (B) \]

\( V \) provides the voltage to \( - \) input of the op-amp. \( V \) will not be a constant voltage but it will vary with intensity of light. During day time, when light is falling upon LDR, \( R_L \) is small. According to eq. (B), \( V \) will be
large such that \( V > V_R \) so that \( V_o = -V_{cc} \). The output of the op-amp is connected with a relay system which energizes only when \( V_o = +V_{cc} \) and then it turns on the street lights. Thus when \( V_o = -V_{cc} \) the light will not be switched ‘ON’.

As it gets darker, \( R_L \) becomes larger and \( V \) decreases. When \( V \) becomes just less than \( V_R \), the output of op-amp switches to \(+V_{cc}\) which energizes the relay system and the street lights are turned ON.

**DIGITAL SYSTEMS**

Defn: “A digital system deals with quantities or variables which have only two discrete values or states.”

**Examples:** Following are the examples of such quantities:

- (i) A switch can be either open or closed.
- (ii) The answer of a question can be either yes or no.
- (iii) A certain statement can be either true or false.
- (iv) A bulb can be either off or on.

Various designations are used to represent the two quantized states of such quantities. The most common of these are listed in the following table:

<table>
<thead>
<tr>
<th>one of the states</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>The other state</td>
<td>False</td>
<td>Low</td>
<td>0</td>
<td>No</td>
<td>off</td>
<td>open</td>
</tr>
</tbody>
</table>
Mathematically, these quantities are represented by binary digits ‘1’ and ‘0’. When we are dealing with voltages, the designation such as ‘High’ or ‘Low’ is a convenient representation.

In describing functions of digital systems a closed switch will be shown as ‘1’ and open switch will be shown as ‘0’. Similarly, a lighted bulb will be described as ‘1’ and an off bulb will be described as ‘0’.

Just as we require two basic mathematical operations, i.e., addition and subtraction for the mathematical manipulation of ordinary quantities, we require a special algebra, known as Boolean algebra for the manipulation of the quantities which have values ‘1’ and ‘0’, now designated as Boolean Variables.

**Boolean Algebra:** “The algebra which deals with ‘Boolean Variables’ is called Boolean Algebra.”

This logical algebra was developed by George Boole. Boolean algebra is based upon three basic operations normally, which are:

(i) **AND operation** (ii) **OR operation** (iii) **NOT operation**

**Fundamental Logic Gates**

**Definition:** “The electronic circuits which implement the various logic operations are known as logic gates.”
In these gates, one particular voltage level represents a high (1) and another voltage level represents a low (0). In practical digital circuits, however, a '1' or high can be any voltage between a specified min. value and a specified max. value. Likewise, '0' or low can be any voltage between a specified min. and a specified max. as shown in Fig.-27.

It shows the range '1' and '0' levels for a certain type of digital gates. Thus if voltage of '3.5V' is applied to a gate, it will accept it as high or 1. If a voltage of 0.5V is applied, the gate will recognize it as '0' or low.

The three important basic logic gates are being discussed here:

1. **OR Gate**: The 'OR gate' is symbolically shown in Fig.-28. It implements the logic of 'OR' operation. The mathematical notation (or Boolean expression) for 'OR' operation is:

   \[ X = A + B \]

   It has two (or more) inputs such as A, B and a single output X. The output has value '1' when at least one of its inputs 'A' and 'B' is at '1.' Thus 'X' will
be zero only when both the inputs are ‘0’ as it can be verified by truth table-1. That is why it is also named as “any-or-all gate”.

(2) **AND Gate**: The symbol of ‘AND gate’ is shown in fig-29. It has two or more inputs and a single output. It implements the logic of ‘AND operation, as shown in Truth Table-2. The ‘Boolean expression’ for AND operation is: \( X = A \cdot B \).

Its output ‘\( X \)’ is ‘1’ only when both of its inputs \( A \) and \( B \) are at ‘1’ and for all other combinations of the values of \( A \) and \( B \), \( X \) is zero. That is why it is also named as “all or nothing” gate.

(3) **NOT Gate**: The symbolic representation of ‘NOT gate’ is shown in fig-30. It performs the operation of inversion or complementation. That is why it is also known as inverter. The Boolean expression for ‘NOT’ operation is: \( X = \overline{A} \).

It changes a logic level to its opposite level i.e., it changes ‘1’ to ‘0’ and ‘0’ to ‘1’. Whenever a bar is placed on any variable, it shows that the value of the variable has been inverted. For example \( \overline{1} = 0 \).
and $\overline{0} = 1$. The "bubble" (O) in fig. 30 indicates operation of inversion. The truth table-3 clears its operation.

OTHER LOGIC GATES:

Some other important logic gates, which are rather combinations of above discussed basic gates are discussed here:

(i) **NOR Gate**: The combination of 'OR' gate with 'NOT' gate is called **NOR gate**. Its symbol is shown in fig. 31. Its mathematical notation (or Boolean expression) is: $X = \overline{A + B}$. In this gate, the output of 'OR' gate is inverted as it is clear from Truth Table-4. That is why it is also called "NOT-OR gate".

(ii) **NAND Gate**: The combination of 'AND' gate with 'NOT' gate is called "NAND gate". Its symbol is shown in fig. 32. The mathematical notation (or Boolean expression) for 'NAND operation' is: $X = \overline{A \cdot B}$. In this gate, the output of 'AND gate' is inverted, as it is shown by the bubble in fig. 32. The truth table-5 clears its operation.

(iii) **Exclusive OR Gate**: 

Construction: Consider a Boolean function $X$ of two variables 'A' and 'B' such that: $X = A \cdot \overline{B} + \overline{A} \cdot B$. 


Def: A gate which is a combination of AND OR and NOT gates is called Exclusive OR gate or XOR.

Symbol:

\[
\text{Input A} \quad \text{Input B} \quad \text{Output X}
\]

Construction and Operation:

The first term of the function \( X \) is obtained by ANDing the variable \( A \) with NOT of \( B \). The second term is NOT of \( A \) ANDing with \( B \). The function \( X \) is obtained by ORing these two terms.

It shows that the value of \( X \) is zero when the two inputs have the same value and it is 1 when the inputs have different values.

Exclusive OR (XOR) can however be extended to more than two inputs.

(iv) Exclusive NOR gate (XNOR)

Def: The gate \( A \) which is obtained by inverting the output of XOR gate is called Exclusive NOR gate.

Symbol:

\[
\text{Input A} \quad \text{Input B} \quad \text{Output X}
\]

Construction and Operation:

It is constructed by a combination of NOT, AND and NOR gates as shown.

(\text{P.T.O.})
fig(a) Exclusive NOR (XNOR) using AND, OR and NOT gates.

The bubble shown at the output indicates that the output of XOR gate has been inverted. Its Boolean expression is

\[ X = \overline{A \cdot B} + \overline{A} \cdot \overline{B} \quad \text{or} \quad X = A \oplus B \quad \text{or} \quad X = A \oplus B \]

The truth table of XNOR gate is given in the table. Its output is 1 when its two inputs are identical and 0 when two inputs are different.

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

fig(b) Equivalence function

Exclusive NOR (XNOR) using two AND, two NOT and one OR gate.

# APPLICATIONS OF GATES IN CONTROL SYSTEMS:

Gates have wide applications in control systems. They control the function of a system by monitoring some physical parameters such as temperature, pressure or some physical quantity of the system.

For example, in power stations, they are used to...
monitor the system that controls the frequency of the A.C generator. In cameras, they monitor the aperture and shutter speed and also monitor the focussing of image in auto-focussing cameras. They are also used in various household washing machines, microwave oven. They also used as Burglar Alarm, automatic lighting, stopwatch, timer, etc.

Since gates operate with electrical voltages only, so some sensors are required:

**SENSORS**

Def: “The devices which converts various physical quantities into electric voltage are called Sensors.”

---

1. In a light switch, a light dependent resistance (LDR) is a sensor for light because it can convert changes in the intensity of light into electric voltage.

2. A thermistor is a sensor for temperature.

3. A microphone is a sound sensor.

4. Similarly, there are level sensors, which give an electrical signal when the level of liquid in a vessel attains a certain limit.

**MONITORING SYSTEM OF PRESSURE AND TEMPERATURE**

Sensors are used to monitor the pressure and temperature of a chemical solution stored in a vat. The circuiting for each sensor is such that it produces HIGH or 1 when either the temperature or pressure exceeds a specific value.

A circuit is to be designed which will ring an alarm.
when either the temperature or pressure or both cross the max. specified limit. The alarm requires a
low or '0' voltage for its activation.

When ever output of the circuit C' is low, the alarm is activated. The table is similar to
NOR gate. Hence the circuit C' should be
NOR gate.

BURGLAR ALARM SYSTEM:
A push switch is placed at some secret point under
the door. The push switch is ON when door is closed
and OFF when it is open. When the circuit is activated
it operates a relay.

AUTOMATIC STREET LIGHT:
A photocell is used at the input of a NOT gate. As
light falls on the photocell or on a LDR during day
time, its output remains 1 making the output of NOT
gate equal to 0. When it is dark the output of
photocell becomes 0" making the output of NOT
gate equal to '1' and the street lights are
turned ON.
**Chapter 20: Electronics**

**CHP. 18**

**SHORT QUESTIONS**

Q 18.1. Electrons are majority carriers and holes are minority carriers in the n-type substances and opposite is the case in the p-type substances. Current is constituted by the flow of electrons (electronic current) in n-type substances and by the flow of holes (conventional current) in p-type substances. Both the currents flow in opposite directions when a battery is put in the circuit.

Q 18.2. Net charge on them is zero and they remain electrically neutral unless a battery is put in the circuit which makes electrons and holes drift in opposite direction.

Q 18.3. When electric potential of anode (p-type) is greater by 0.2V w.r.t cathode (n-type) then such pn junction is called forward biased, as the electrons always move from a lower potential to a higher potential.

Q 18.4. An n-region contains free electrons as majority charge carriers and p-region contains holes as majority charge carriers, just after the formation of the junction. The free electrons in the n-region because of their random motion, diffuse into the p-region. As a result of their diffusion, a chargeless region is formed around the junction in which the charge carriers are not present. So it offers resistance for the flow of current.

(P.T.O)
Q18.5. Forward biasing will reduce the width of depletion region whereas reverse biasing will increase the width of depletion region.

Q18.6. This is because silicon is opaque to light. REASON: During forward bias conduction in a LED, the electron undergoes an energy change before combining with the hole. The energy radiated by the electron appears as light. In ordinary silicon diode, this radiated energy is very small. So no visible light is seen due to the transition of electron i.e.; the ordinary silicon diode does not emit light because it has low value of forward bias as compared to LED.

Q18.7. Photodiode is used for detection of light. When no light falls on the reverse biased junction of the photodiode, no current flows. But when light falls on it the electron and hole pairs are generated due to disruption of covalent bonds. Due to which the diode starts conducting. Hence it is always reverse biased. When p-n junction is exposed to light, the reverse current increases with the intensity of light as shown in fig. 

Q18.8. The base region has very small doping level as compared to emitter and collector. This means that it has very few number of holes or electrons in it. When electrons or holes enter into the base region from emitter, the number of recombination of
These charges with the charges already present in the base is small. Thus base current is also small.

Q18.9. For its normal operation the input junction is always forward biased while the output junction is reverse biased. In case of common-emitter amplifier, input is applied between base and emitter. The output is obtained between collector and emitter. Hence emitter-base junction is always forward biased and collector-base junction is always reverse biased.

Q18.10. In an inverting amplifier, input signal voltage $V_i$ to be amplified is applied at inverting terminal ($-$) through resistance and $V_o$ is the output voltage. The non-inverting terminal is grounded and its potential is zero. Since $V_+$ is at ground potential so $V_-$ is virtually at ground potential i.e. $V_- = 0$.

The open loop voltage gain of this amplifier is about $10^5$ i.e.

$$A_{OL} = \frac{V_o}{V_i} = 10^5$$

As $V_o = V_+ + (-V_o) = 0 - V_- = -V_-$, so

$$A_{OL} = \frac{-V_o}{-V_-} = \frac{V_o}{V_-} = 10^5 \quad \text{or} \quad V_- = 0$$

That is $V_-$ is virtually at ground potential. This is called principle of virtual ground (input is virtually at ground potential).

**Voltage gain.** Current through $R_1 = I_1 = \frac{V_i - V_-}{R_1} = \frac{V_i}{R_1}$

$q$. Current through $R_2 = I_2 = \frac{V_o - V_+}{R_2} = \frac{0 - V_o}{R_2} = \frac{-V_o}{R_2}$

(P.T.O.)
Using Kirchhoff's current rule:

\[ \frac{I_1}{V_2} = \frac{Y_0}{R_2} \]

or \[ G = \frac{V_0}{V_2} = -\frac{R_2}{R_1} \]

which is the voltage gain of inverting amplifier.

Q18.11: For input \( A=1, B=0 \),

(a) output = 0

then the gate is either an AND gate or XNOR gate.

(b) output = 1

The gate may be an OR gate, NAND gate or XOR gate.

Q18.12:

(i) c (ii) d (iii) d (iv) a (v) b (vi) c

(vii) a (viii) d (ix) a

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Chapter 20: Electronics

P.18.2
DATA: \( I_C = 10 \text{ mA} = 10^{-2} \text{ A} \)  collector current

\[
\text{current gain} = \beta = 200
\]

Base emitter voltage \( V_{BE} = 0.6 \text{ V} \)

\( V_{CC} = 9 \text{ V} \)

\( R_B = ? \)

\[ \text{Sol.} \quad \beta = \frac{I_C}{I_B} \]

\[ I_B = \frac{I_C}{200} = 0.5 \times 10^{-4} \text{ A} \]

\[ \text{We know that} \]

\[ V = V_{CC} - V_{BE} \]

\[ V = 9 - 0.6 = 8.4 \text{ volt} \]

Using the relation:

\[ V = I_B R_B \]

\[ R_B = \frac{V}{I_B} = \frac{8.4}{0.5 \times 10^{-4}} = 16.8 \times 10^4 \Omega \]

\[ R_B = 16.8 \text{ K}\Omega \]

P.18.3
DATA: \( V_{CC} = 9 \text{ V} \)

\( V_{CE} = 7.875 \text{ V} \)

\( R_C = 1 \text{ K}\Omega = 10^3 \Omega \)

\( R_B = 100 \text{ K}\Omega = 10^5 \Omega \)

\( \beta = 100 \)

(i) Base current \( I_B = ? \)

(ii) Collector current \( I_C = ? \)

(iii) Potential drop across \( R_C = V_C = ? \)

\[ \text{Sol.} \]

(ii) Potential drop across \( R_C = V_{CE} - V_C \)

\[ I_C = \frac{V_{CC} - V_{CE}}{R_C} = \frac{9 - 7.875}{10^3} = 1.125 \times 10^{-3} \text{ A} = 1.125 \text{ mA} \]

(i) put \( \beta = \frac{I_C}{I_B} \)

\[ I_B = \frac{I_C}{\beta} = \frac{1.125 \times 10^{-3}}{100} = 11.25 \times 10^{-6} \text{ A} \]

\[ I_B = 11.25 \mu\text{A} \]

(P.T.O.)


Chapter 20: Electronics

\[ \text{Potential drop across } R_c = \frac{1.125V}{1.125} \]

OR

\[ \text{Potential drop across } R_c = I_c R_c = \frac{1.125 \times 10^{-3} \times 10}{1} = 1.125V \]

**P.18.4:**

**DATA:**
- \( R_1 = 10 \, \text{k}\Omega = 10 \times 10^3 \, \Omega \)
- \( R_2 = 4 \, \text{k}\Omega = 4 \times 10^3 \, \Omega \)
- Output of op-amp circuit = \( V_o = ? \)

**Sol.**
Using Kirchhoff's law:

\[ \sum (\text{current through}) + \sum (\text{current through}) = \sum (\text{current through}) \]

\[ I = \text{current through } R_1 = \frac{(5 - 0)V}{10 \times 10^3} = 0.5 \times 10^{-3} \, A \]  

\[ I_2 = \text{current through } R_2 = \frac{-2V - 0}{4 \times 10^3} = -0.5 \times 10^{-3} \, A \]

\[ I = \text{Total current through } R_3 = I_1 + I_2 \]

\[ = 0.5 \times 10^{-3} - 0.5 \times 10^{-3} = 0 \]

\[ \therefore V_o = \text{output} = 0 \]

\[ I = \frac{V_o - 0}{R_3} = \frac{V_o}{2 \times 10^3} \]

\[ 0 = \frac{V_o}{2 \times 10^3} \]

\[ V_o = 0 \]

**P.18.5:**

**DATA:**
- \( R_1 = 10 \, \text{k}\Omega = 10 \times 10^3 \, \Omega \)
- \( R_2 = 40 \, \text{k}\Omega = 40 \times 10^3 \, \Omega \)
- Gain of non-inverting amplifier = \( G = ? \)

**Sol.**
Using the rel:

\[ G = 1 + \frac{R_2}{R_1} \]

\[ = 1 + \frac{40 \times 10^3}{10 \times 10^3} \]

\[ = 1 + 40 \]

\[ G = 1 + 4 = 5 \]
Chapter 20: Electronics

PROBLEMS

P. 18.1

DATA

\[ I_B = 100 \mu A = 100 \times 10^{-6} = 10^{-4} A \]
\[ B = 100 \]

(i) Current flowing through collector = \( I_C = ? \)

(ii) Current flowing through emitter = \( I_E = ? \)

(iii) \( I_C / I_B = ? \)

Sol. (i) As \( \frac{I_C}{I_B} = B = 100 \)

\[ I_C = 100 \times I_B = 100 \times 10^{-4} = 10^{-2} A = 10 mA \]

(ii) \[ I_E = I_C + I_B = 10^{-2} + 10^{-4} = 10^{-2} (1 + 0.01) A \]
\[ = 10^{-2} (1.01) A = 10^{-2} \times 10^{-3} mA \]
\[ = 10^{-5} (1.01) = 10.01 mA \]

(iii) \[ \frac{I_C}{I_E} = \frac{10 mA}{10.01 mA} = 0.999 \]


**Chapter 20: Electronics**

**P.18.2**

**DATA:**
- $I_c = 10\,mA = 10^{-2}\,A$ = collector current
- $\beta = 200$ = current gain
- $V_{BE} = 0.6\,V$ = base emitter voltage
- $V_{cc} = 9\,V$
- $R_B = ?$

**Sol.**

1. $I_B = \frac{I_c}{\beta} = \frac{10^{-2}}{200} = 0.5 \times 10^{-4}\,A$

We know that

2. $V = V_{cc} - V_{BE}$

3. $V = 9 - 0.6 = 8.4\,\text{volt}$

Using the relation:

4. $V = I_B R_B$

5. $R_B = \frac{V}{I_B} = \frac{8.4}{0.5 \times 10^{-4}} = 16.8 \times 10^4\,\Omega$

6. $R_B = 16.8\,\text{k}\Omega$

**P.18.3**

**DATA:**
- $V_{cc} = 9\,V$
- $V_{CE} = 7.875\,V$
- $R_e = 1\,\text{k}\Omega = 10^3\,\Omega$
- $R_B = 100\,\text{k}\Omega = 10^5\,\Omega$
- $\beta = 100$

(i) Base current $I_B = ?$

(ii) Collector current $I_c = ?$

(iii) Potential drop across $R_C = V_C = ?$

**Sol.**

(iii) Potential drop across $R_C = V_{cc} - V_{CE}$

\[ I_C = \frac{V_{cc} - V_{CE}}{R_C} = \frac{9 - 7.875}{10^3} = 1.125 \times 10^{-3}\,A = 1.125\,mA \]  

(i) put $\beta = \frac{I_c}{I_B}$

or $I_B = \frac{I_c}{\beta} = \frac{1.125 \times 10^{-3}}{100} = 11.25 \times 10^{-6}\,A = 11.25\,\mu A$

(P.T.O.)
Chapter 20: Electronics

(iii) Potential drop across $R_c = \frac{1.125 \text{ V}}{10} = 0.1125 \text{ V}$

OR

Potential drop across $R_c = I_c R_c = 1.125 \times 10^{-3} \times 10$

$= 1.125 \text{ V}$

P.18.4:

**DATA**

$R_1 = 10 \, \text{k}\Omega = 10 \times 10^3 \, \Omega$

$R_2 = 4 \, \text{k}\Omega = 4 \times 10^3 \, \Omega$

Output of op-amp circuit = $V_o = ?$

**Sol.** Using Kirchhoff's law

\[
\text{(current through)} R_1 + \text{(current through)} R_2 = \text{(current through)} R_3
\]

$I_1 = \text{Current through } R_1 = \frac{(5 - 0) \text{ V}}{10 \times 10^3} = 0.5 \times 10^{-3} \text{ A} \quad \text{(1)}$

$I_2 = \text{Current through } R_2 = \frac{-2 \text{ V} - 0}{4 \times 10^3} = -0.5 \times 10^{-3} \text{ A} \quad \text{(2)}$

$I = \text{Total current through } R_3 = I_1 + I_2$

$= 0.5 \times 10^{-3} - 0.5 \times 10^{-3} = 0$

$\therefore V_o = \text{output} = 0$

$I = \frac{V_o - 0}{R_3} = \frac{V_o}{2 \times 10^3}$

$0 = \frac{V_o}{2 \times 10^3}$

$V_o = 0$

P.18.5:

**DATA:**

$R_1 = 10 \, \text{k}\Omega = 10 \times 10^3 \, \Omega$

$R_2 = 40 \, \text{k}\Omega = 40 \times 10^3 \, \Omega$

Gain of non inverting amplifier = $G = ?$

**Sol.** Using the rel.

$G = 1 + \frac{R_2}{R_1} = 1 + \frac{40 \times 10^3}{10 \times 10^3}$

$= 1 + 4$

$G = 5$