Electronic Devices

Energy Bands in Solids

According to band theory of solids, in a crystalline solid due to mutual interaction among valence electrons of neighbouring atoms, instead of sharp energy levels, energy bands are formed. Energy bands are of the following three types

(i) **Valence band** It is the energy band formed by a series of energy levels of valence electrons actually present. Ordinarily, valence band is completely filled and electrons in this band are unable to gain energy from external electric field. The highest energy level in a valence band at 0 K is called **fermi energy level**.

(ii) **Conduction band** The energy band having just higher energy than the valence band is called conduction band. Electrons in conduction band are commonly called the free electrons.

(iii) **Forbidden band** The energy gap between the valence band and the conduction band of a solid is called the **forbidden energy gap** E_g or forbidden band. Width of forbidden energy gap depends upon the nature of substance.

Semiconductors

- In semiconducting solids, the valence band is completely filled but conduction band is completely empty and the energy gap between them is small enough ($E_g < 3$ eV). At absolute zero temperature, it behaves as an **insulator**.

- A pure semiconductor, in which no impurity of any sort has been mixed, is called **intrinsic semiconductor**. Germanium ($E_g = 0.72$ eV) and silicon ($E_g = 1.1$ eV) are examples of intrinsic semiconductors.

- Electrical conductivity of pure semiconductor is very small. To increase the conductivity of a pure semiconducting material, it is doped with a controlled quantity (1 in 10^5 or 10^6) of suitable impurity. Such a doped semiconductor is called an **extrinsic semiconductor.**

- The number of electrons reaching from valence band to conduction band,

$$n = AT^{3/2} e^{-E_g/2kT}$$

where, $k =$ Boltzmann's constant, $T =$ absolute temperature and $A =$ atomic weight.

Superconductors

When few metals are cooled, then below a certain critical temperature, their electrical resistance suddenly becomes zero. In this state, these substances are called **superconductors** and this phenomena is called **superconductivity**. Mercury become superconductor at 4.2 K, lead at 7.25 K and niobium at 9.2 K.

Types of Extrinsic Semiconductor

According to type of doping impurities, extrinsic semiconductor are of two types

1. n-type Semiconductor

To prepare an *n*-type semiconductor, a pentavalent impurity, e.g. P, As, Sb is used as a dopant with Si or Ge.

Such an impurity is called **donor impurity**, because each dopant atom provides one **free electron**.

In *n*-type semiconductor $n_e >> n_h$, i.e. electrons are majority charge carriers and the holes are minority charge carriers, such that $n_e \cdot n_h = n_i^2$. An *n*-type semiconductor is electrically neutral and is not negatively charged.

Conductivity, $\qquad \sigma \approx n_e \mu_e e$

2. p-type Semiconductor

To prepare a *p*-type semiconductor, a trivalent impurity, e.g. B, Al, In, Ga, etc., is used as a dopant with Si or Ge. Such an impurity is called **acceptor impurity** as each impurity atom wants to accept an electron from the crystal lattice. Thus, effectively each dopant atom provides a **hole**.

In *p*-type semiconductor $n_h >> n_e$, i.e. holes are majority charge carriers and electrons minority charge carriers, such that $n_h \cdot n_e = n_i^2$. A *p*-type semiconductor is electrically neutral and is not positively charged.

The number of free electrons in a semiconductor varies with temperature as $T^{3/2}$.

Conductivity, $\qquad \sigma \approx n_h \mu_h e$

Semiconductor Diode

A **p-n junction** is obtained by joining a small *p*-type crystal with a small *n*-type crystal without employing any other binding material in between them. Whenever a *p-n* junction is formed, electrons from *n*-region diffuse through the junction into *p*-region and the holes from *p*-region diffuse into *n*-region.

As a result of which neutrality of both *n* and *p*-regions is disturbed, and a thin layer of immobile negative charged ions appear near the junction in the *p*-crystal and a layer of positive ions appear near the junction in *n*-crystal.

This layer containing immobile ions is called **depletion layer**. The thickness of depletion layer is approximately of the order of 10^{-6} m.

The potential difference developed across the *p-n* junction due to diffusion of electrons and holes is called the **potential barrier** V_b (or emf of fictitious battery). For germanium diode barrier potential is 0.3 V, but for Si diode, its value is 0.7 V. The barrier electric field developed due to it, is of the order of 10^5 Vm^{-1}.

Mobility of Charge Carriers

The mobility of a charge carrier is defined as the velocity gained by its per unit electric field, i.e. $\mu = V_d/E$.

- Current in semiconductor is, $i = i_e + i_h = eA(n_e V_e + n_h V_h)$

  Conductivity, $\sigma = \dfrac{J}{E} = \dfrac{i}{AE} = e(n_e \mu_e + n_h \mu_h)$

  (where, $J =$ current density $= nqV$)

I-V Characteristics of Semiconductor Diode in Forward and Reverse Bias

When we join an external potential source, such that *p*-side of *p-n* junction is joined to positve terminal of voltage source and *n*-side to negative terminal of voltage source, the junction is said to be **forward biased** and applied electric field E opposes the barrier electric field E_b.

As a result, width of depletion layer is reduced and on applying a voltage $V > V_b$, a forward current begins to flow. Resistance offered by *p-n* junction in forward bias is small (about 10-50 Ω).

(a) FB   (b) RB   (c)
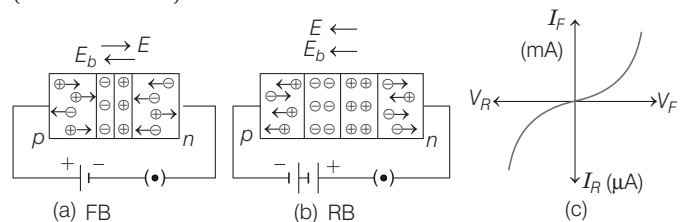
If connections of potential source are reversed [Fig. (b)], i.e. *p* -side is connected to negative terminal of battery and *n*-side to positive terminal, the junction is said to be **reverse biased** and in this case E and E_b, being in same direction, are added up. So, the depletion layer broadens and potential barrier is fortified. Consequently, an extremely small leakage current flows across the junction due to minority charge carriers and junction resistance is extremely high ($\approx 10^5$ Ω). For a sufficiently high reverse bias voltage (25 V or even more), the reverse current suddenly increases. This voltage is called **Zener voltage** or **breakdown voltage** or **avalanche voltage**.

NOTE
- A *p-n* junction behaves as a voltage controlled switch. In forward bias, it acts like ON switch and in reverse bias as OFF switch.
- The *p-n* junction can be presumed as a capacitor, in which the depletion layer acts as dielectric.

Diode as a Rectifier

Junction diode allows current to pass only when it is forward biased. So, if an alternating voltage is applied across a diode, the current flows only in that part of the cycle, when the diode is forward biased.

This property is used to rectify alternating voltages and the circuit used for this purpose is called a rectifier, and the process is known as rectification.

There are two types of rectifier diode as given below

1. **Half Wave Rectifier** A rectifier, which rectifies only one-half of each AC input supply cycle, is called a **half wave rectifier.**

   A half wave rectifier gives discontinuous and pulsating DC output. As no output is obtained corresponding to alternate half cycles of the AC input supply, its efficiency is quite low.

2. **Full Wave Rectifier** A rectifier, which rectifies both halves of each AC input cycle is called a full wave rectifier.

   The output of a full wave rectifier is continuous, but pulsating in nature. However, it can be made smooth by using a filter circuit.

   As output is obtained corresponding to both the half cycles of the AC input supply, its efficiency is more than that of half wave rectifier.

NOTE
  • The ripple factor is defined as the ratio of rms value of AC component in the output of the rectifier to the DC component in the input.

Special Purpose Diodes

There are few diodes which are designed to serve some special purpose and application.

Zener Diode

It is a highly doped *p-n* junction diode which is not damaged by high reverse current. It is always used in reverse bias in breakdown voltage region and is chiefly used as a voltage regulator.

• **Zener Diode as Voltage Regulator** The following circuit is used for stabilising voltage across a load R_L. The circuit consists of a series voltage-dropping resistance R and a Zener diode in parallel with the load R_L.
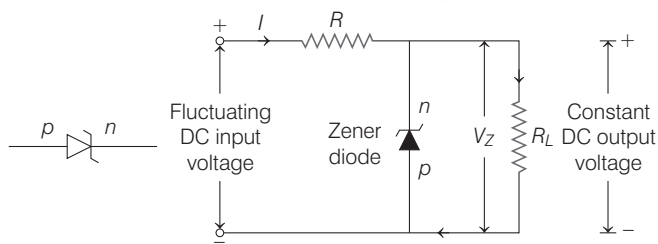
The Zener diode is selected with Zener voltage V_z equal to the voltage desired across the load.

Light Emitting Diode (LED)

It is a specially designed diode made of GaAsP, GaP, etc. When used in forward biased, it emits characteristic, almost monochromatic light. In reverse biased, it works like a normal diode.

• **I-V Characteristics** LEDs are current dependent devices with its forward voltage drop (V_F) depending on the forward biased LED current. Characteristics of light emitting diode *I-V* are shown below
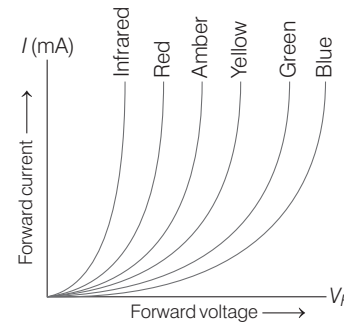
Photodiode

It is a special diode used in reverse bias which conducts only when light of suitable wavelengths is incident on the junction of diode. The energy of incident light photon must be greater than the band gap of semiconductor (i.e. $h\nu > E_g$). Materials used are Cds, Se, Zns, etc.

Solar Cell

It is a special *p-n* junction, in which one of the semiconductors is made extremely thin, so that solar radiation falling on it reaches junction of diode without any absorption. A solar cell directly converts, solar energy into electrical energy. Popularly used solar cells, Ni-cd, PbS cell, etc.

Transistor

A transistor is a combination of two *p-n* junctions joined in series. A junction transistor is known as **Bipolar Junction Transistor** (BJT). It is a three terminal device.

Transistors are of two types

(i) *n-p-n* transistor,

(ii) *p-n-p* transistor

A transistor has three regions

(i) An **emitter** (*E*), which is most heavily doped, and is of moderate size. It supplies large number of charge carriers, which are free electrons in an *n-p-n* transistor and holes in a *p-n-p* transistor.

(ii) A **base** (*B*), which is very lightly doped and is very thin (thickness $\approx 10^{-5}$m).

(iii) A **collector** (*C*), which is moderately doped and is thickest.

A transistor is symbolically represented as shown in figures.

(a)   (b)
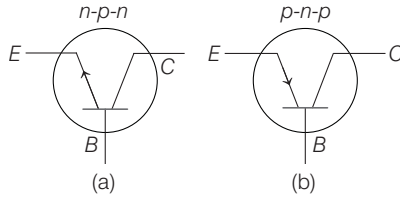
Transistor Action

For proper functioning of a transistor, the **emitter-base junction is forward biased**, but the **collector-base junction** is **reverse biased.** In an *n-p-n* transistor, electrons flow from emitter towards the base and constitute a current I_E.

Due to larger reverse bias at base-collector junction, most of these electrons further pass into the collector, constituting a collector current I_C. But a small percentage of electrons (less than 5%) may combine with holes present in base. These electrons constitute a base current I_B. It is self evident, that

$$I_E = I_C + I_B.$$

Action of *p-n-p* transistor is also same, but with one difference that holes are moving from emitter to base and then to collector.

A transistor can be connected in either of the following three configurations

  (i) Common Emitter (CE) configuration

  (ii) Common Base (CB) configuration

  (iii) Common Collector (CC) configuration.

Generally, we prefer common emitter configuration, because power gain is maximum in this configuration.

Characteristics of a Transistor

In common emitter configuration, variation of current on the input side with input voltage (I_B *versus* V_{BE}) is known as the **input characteristics**, and the variation in the output current with output voltage (I_C *versus* V_{CE}) is known as **output characteristics**. From these characteristics, we obtain the values of following parameters

- Input resistance, $r_i = \left| \dfrac{\Delta V_{BE}}{\Delta I_B} \right|_{V_{CE} = \text{constant}}$

- Output resistance, $r_o = \left| \dfrac{\Delta V_{CE}}{\Delta I_C} \right|_{I_B = \text{constant}}$

- AC current gain, $\quad \beta = \left| \dfrac{\Delta I_C}{\Delta I_B} \right|_{V_{CE} = \text{constant}}$

   The current gain for common-emitter configuration β ranges from 20 to 200.

- Transconductance, $g_m = \dfrac{\Delta I_C}{\Delta V_{BE}} = \dfrac{\beta}{r_i}$

- A transistor can be used as an amplifier. The voltage gain of an amplifier will be given by

   $A_V = \dfrac{V_o}{V_i} = \beta \cdot \dfrac{R_C}{R_B}$

   where, R_C and R_B are net resistances in collector and base circuits, respectively.

- In common base configuration, AC current gain is defined as $\alpha = \left| \dfrac{\Delta I_C}{\Delta I_E} \right|_{V_{CE} = \text{constant}}$

- Value of α is slightly less than 1. In fact, $0.95 \le \alpha \le 1$.

- Power gain $= \dfrac{\Delta P_o}{\Delta P_i} = \beta^2_{AC} \times \text{Resistance gain}$

NOTE • Current gains α and β are correlated as

    $\beta = \dfrac{\alpha}{1 - \alpha} \quad \text{or} \quad \alpha = \dfrac{\beta}{1 + \beta}$

Transistor as an Amplifier

A transistor consisting of two *p-n* junctions, one forward biased and the other reverse biased can be used to amplify a weak signal. The forward biased junction has a low resistance path, whereas the reverse biased junction has a high resistance path. The weak input signal is applied across the forward biased junction, and the output signal is taken across the reverse biased junction.
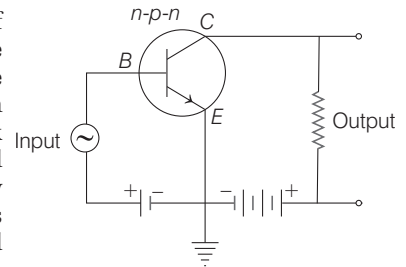
Since, the input and output currents are almost equal, the output signal appears with a much higher voltage. The transistor, thus acts as an amplifier. Common-emitter configuration of transistor amplifier is given alongside.

Transistor as an Oscillator

An electronic oscillator is a device that generates electrical oscillations of constant amplitude and of a desired frequency, without any external input.

The circuit providing such oscillation, is known as a tank oscillator, is using positive feedback.
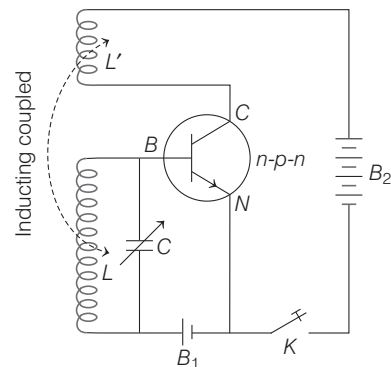

Some of the properties of the oscillator are

- Oscillator is using positive feedback.

- To work as an oscillator,
   $|A\beta| = 1; \beta \rightarrow \text{feedback factor}$

- $f = \text{frequency of oscillation} = \dfrac{1}{2\pi} \times \dfrac{1}{\sqrt{LC}}$.

FOUNDATION QUESTIONS EXERCISE

1 The conductivity of a semiconductor increases with increase in temperature because

(a) number density of free current carriers increases
(b) relaxation time increases
(c) Both number density of carriers and relaxation time increases
(d) number density of current carriers increases, relaxation time decreases but effect of decrease in relaxation time is much less than increase in number of density

2 Carbon, silicon and germanium atoms have four valence electrons each. Their valence and conduction bands are separated by energy band gaps represented by $(E_g)_C, (E_g)_{Si}$ and $(E_g)_{Ge}$, respectively. Which one of the following relationship is true in their case?

(a) $(E_g)_C > (E_g)_{Si}$ (b) $(E_g)_C = (E_g)_{Si}$
(c) $(E_g)_C < (E_g)_{Ge}$ (d) $(E_g)_C < (E_g)_{Si}$

3 In *n*-type silicon, which of the following statement is true

(a) Electrons are majority carriers and trivalent atoms are the dopants
(b) Electrons are minority carriers and pentavalent atoms are the dopants
(c) Holes are minority carriers and pentavalent atoms are the dopants
(d) Holes are majority carriers and trivalent atoms are the dopants

4 Carbon, silicon and germanium have four valence electrons each. At room temperature, which one of the following statements is most appropriate? ➙ **AIEEE 2012**

(a) The number of free conduction electrons is significant in C but small in Si and Ge
(b) The number of free conduction electrons is negligibly small in all the three
(c) The number of free electrons for conduction is significant in all the three
(d) The number of free electrons for conduction is significant only in Si and Ge but small in C

5 If the lattice constant of this semiconductor is decreased, then which of the following is correct? ➙ **AIEEE 2010**


Conduction bandwidth — E_c
Band gap — E_g
Valence bandwidth — E_v
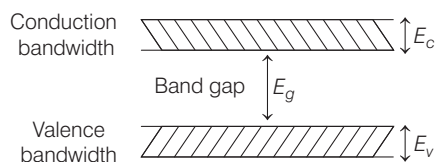
(a) All E_c, E_g and E_v increases
(b) E_c and E_v increases, but E_g decreases

(c) E_c and E_v decreases, but E_g increases
(d) All E_c, E_g and E_v decreases

6 In an unbiased *p-n* junction, holes diffuse from the *p*-region to *n*-region because

(a) free electrons in the *n*- region attract them
(b) they move across the junction by the potential difference
(c) hole concentration in *p*-region is more as compared to *n*-region
(d) All of the above

7 Application of a forward bias to a *p-n* junction

(a) increases the number of donors on the *n*-side
(b) increases the electric field in the depletion zone
(c) increases the potential difference across the depletion zone
(d) widens the depletion zone

8 When forward bias is applied to a *p-n* junction, what happens to the potential barrier V_B and the width of charge depleted region x?

(a) V_B increases, x decreases
(b) V_B decreases, x increases
(c) V_B increases, x increases
(d) V_B decreases, x decreases

**9** The temperature (T) dependence of resistivity (ρ) of a semiconductor is represented by
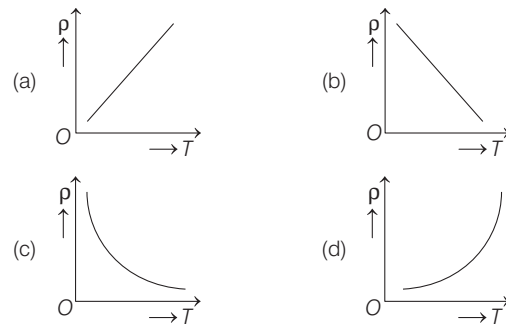
10 In figure, V_0 is the potential barrier across a *p-n* junction, when no battery is connected across the junction.
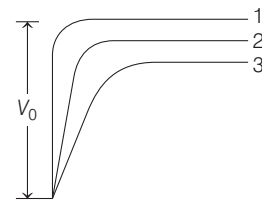
(a) 1 and 3 both corresponds to forward bias of junction

(b) 3 corresponds to forward bias of junction and 1 correspond to reverse bias of junction

(c) 1 corresponds to forward bias and 3 corresponds to reverse bias of junction

(d) 3 and 1 both corresponds to reverse bias of junction

**11** For the given circuit of *p-n* junction diode, which of the following statements is correct?
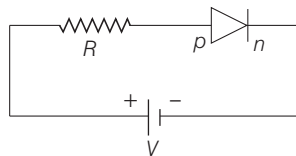
(a) In forward biasing the voltage across R is V
(b) In forward biasing the voltage across R is $2\,V$
(c) In reverse biasing the voltage across R is V
(d) In reverse biasing the voltage across R is $2\,V$

12 In the case of forward biasing of *p-n* junction, which one of the following figures correctly depicts the direction of the flow of charge carriers?

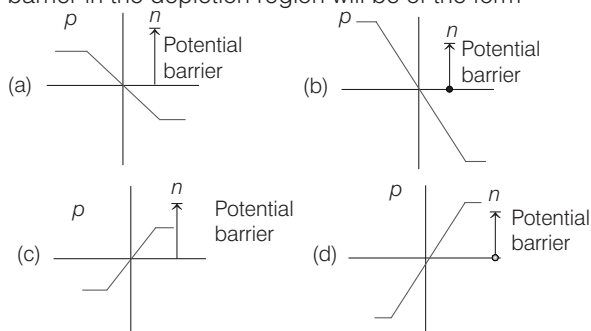(a)

(b)

(c)

(d) None of these
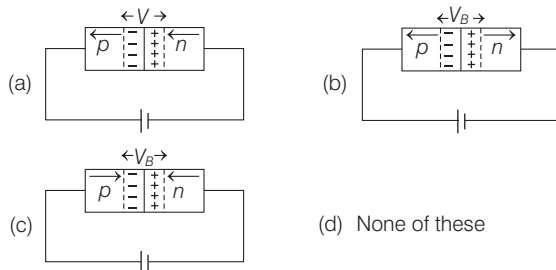
13 A junction diode is connected to a 10 V source and $10^3\,\Omega$ rheostat figure. The slope of load line on the characteristic curve of diode will be
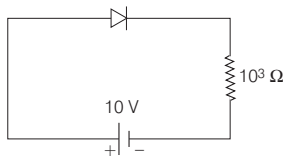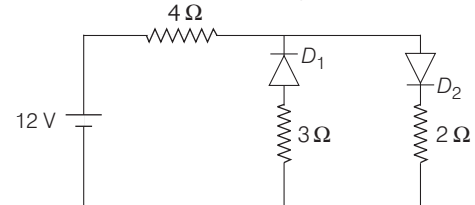

(a) $10^{-2}\,\text{AV}^{-1}$ (b) $10^{-3}\,\text{AV}^{-1}$ (c) $10^{-4}\,\text{AV}^{-1}$ (d) $10^{-5}\,\text{AV}^{-1}$

14 In a forward biased *p-n* junction diode, the potential barrier in the depletion region will be of the form
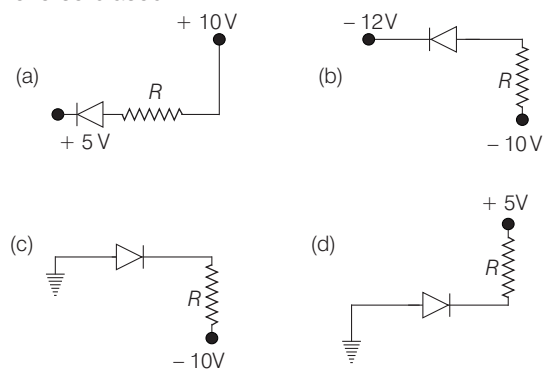

(a)

(b)

(c)

(d)

15 The circuit has two oppositely connected ideal diodes in parallel. What is the current flowing in the circuit?
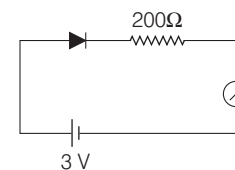

(a) 1.71 A   (b) 2.00 A   (c) 2.31 A   (d) 1.33 A

16 In the following circuits, which one of the diodes is reverse biased?

(a)

(b)

(c)

(d)

17. The forward biased diode connection is   → **JEE Main 2014**

(a) 2V ——▷|——ww——+4V

(b) –2V ——▷|——ww——+2V

(c) +2V——▷|——ww——–2V

(d) –3V ——▷|——ww——–3V

18 The reading of the ammeter for a silicon diode in the given circuit is   → **JEE Main 2018**
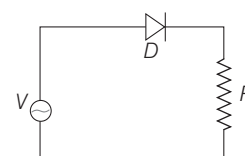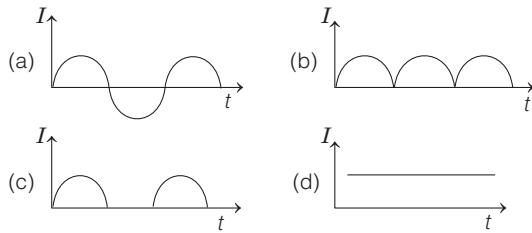

(a) 0   (b) 15 mA   (c) 11.5 mA   (d) 13.5 mA

19 In a full-wave rectifier circuit operating from 50 Hz mains frequency, the fundamental frequency in the output would be

(a) 50 Hz   (b) 25 Hz   (c) 100 Hz   (d) 70.7 Hz

20 A *p-n* junction (*D*) shown in the figure can act as a rectifier. An alternating current source (*V*) is connected in the circuit.   → **AIEEE 2013**
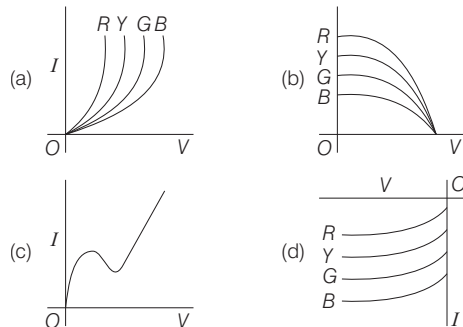
(a), (b), (c), (d) graphs of I vs t

21 Zener breakdown in a semiconductor diode occurs, when

(a) forward current exceeds certain value
(b) reverse bias exceeds certain value
(c) forward bias exceeds certain value
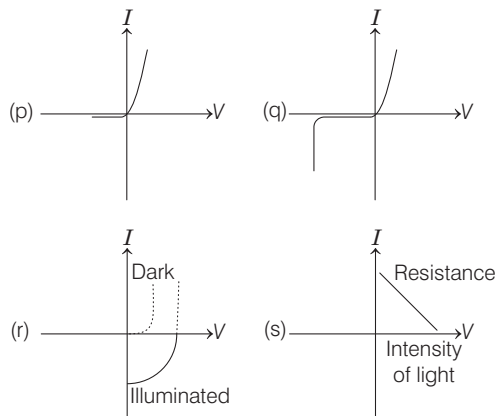(d) potential barrier is reduced to zero

22 The *I-V* characteristics of an LED is   → **AIEEE 2013**

(a), (b), (c), (d) graphs

23 Identify the semiconductor devices whose characteristics are as given below, in the order (p),(q),(r),(s).   → **JEE Main 2016 (Offline)**

(p), (q), (r), (s) graphs

Choose the correct order

(a) Simple diode, Zener diode, Solar cell, Light dependent resistance
(b) Zener diode, Simple diode, Light dependent resistance, Solar cell
(c) Solar cell, Light dependent resistance, Zener diode, Simple diode
(d) Zener diode, Solar cell, Simple diode, Light dependent resistance

24 In a common emitter amplifier circuit using an *n-p-n* transistor, the phase difference between the input and the output voltages will be   → **JEE Main 2017 (Offline)**

(a) 90°   (b) 135°   (c) 180°   (d) 45°

25 When *A* is the internal stage gain of an amplifier and *B* is the feedback ratio, then the amplifier becomes as oscillator if

(a) *B* is negative and magnitude of *B* = *A* / 2
(b) *B* is negative and magnitude of *B* = 1/ *A*
(c) *B* is negative and magnitude of *B* = *A*
(d) *B* is positive and magnitude of *B* = 1/ *A*

Direction (Q. Nos. 26-30) *Each of these questions contains two statements : Statement* I *and Statement* II. *Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes* (a), (b), (c) *and* (d) *given below.*

(a) Statement I is true, Statement II is true; Statement II is the correct explanation for Statement I
(b) Statement I is true, Statement II is true; Statement II is not the correct explanation for Statement I
(c) Statement I is true; Statement II is false
(d) Statement I is false; Statement II is true

26 **Statement I** If forward current changes by 1.5 mA when forward voltage in semiconductor diode is changed from 0.5 V to 2 V, the forward resistance of diode will be 1 Ω.

Statement II The forward resistance is given by $R_f = \dfrac{\Delta V_f}{\Delta I_f}$

27 **Statement I** A Zener diode is used to get constant voltage at variable current under reverse bias.

Statement II The most popular use of Zener diode is as voltage regulator.

28 **Statement I** Light Emitting Diode (LED) emits spontaneous radiation.

Statement II LED are forward biased *p-n* junctions.

29 **Statement I** When base region has larger width, the collector current increases.

Statement II Electron-hole combination in base results in increases of base current.

30 **Statement I** In a common-emitter transistor amplifier the input current is much less than output current.

Statement II The common-emitter transistor amplifier has very high input impedance.

PROGRESSIVE QUESTIONS EXERCISE

1 The input resistance of a common-emitter transistor amplifier, if the output resistance is 500 k Ω, the current gain $\alpha = 0.98$ and the power gain is 6.0625×10^6 is

  (a) 198 Ω (b) 300 Ω (c) 100 Ω (d) 400 Ω

2 If the resistivity of copper is 1.7×10^{-6} Ω-m, then the mobility of electrons in copper, if each atom of copper contributes one free electron for conduction is [the atomic weight of copper is 63.54 and density is 8.96 g/cc]

  (a) 23.36 cm^2/ Vs   (b) 503.03 cm^2/ Vs
  (c) 43.25 cm^2/ Vs   (d) 88 cm^2/ Vs

3 A red LED emits light at 0.1 W uniformly around it. The amplitude of the electric field of the light at a distance of 1 m from the diode is   **➜ JEE Main 2015**

  (a) 1.73 V/m   (b) 2.45 V/m
  (c) 5.48 V/m   (d) 7.75 V/m

4 A working transistor with its three legs marked P, Q and R is tested using a multimeter.

No conduction is found between P and Q. By conneting the common (negative) terminal of the multimeter to R and the other (positive) terminal to P or Q. Some resistance is seen on the multimeter. Which of the following is the true for the transistor?   **➜ AIEEE 2013**

  (a) It is an n-p-n transistor with R as base
  (b) It is a p-n-p transistor with R as collector
  (c) It is a p-n-p transistor with R as emitter
 (d) It is an n-p-n transistor with R as collector

5 A piece of copper and another of germanium are cooled from room temperature to 77 K, the resistance of

  (a) each of them increases
  (b) each of them decreases
  (c) copper decreases and germanium increases
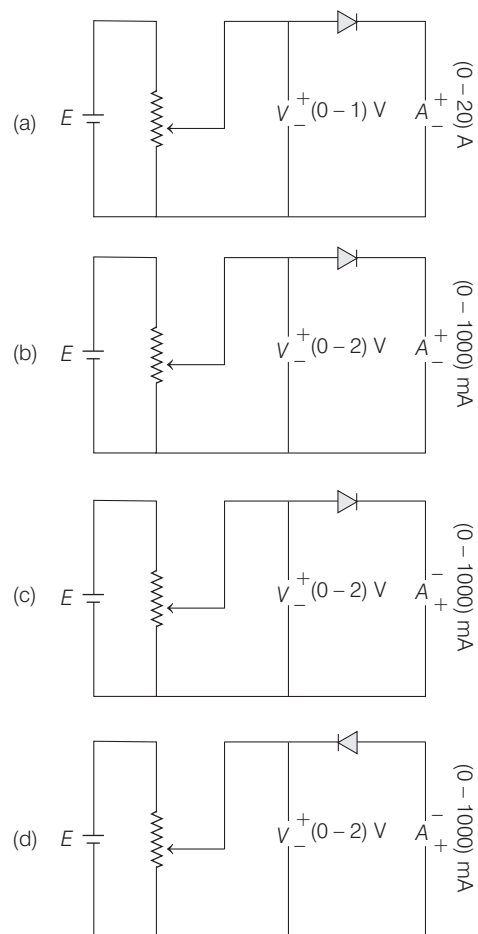 (d) copper increases and germanium decreases

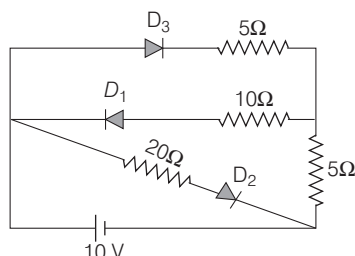**6** If in a p-n junction diode, a square input signal of 10 V is applied as shown.
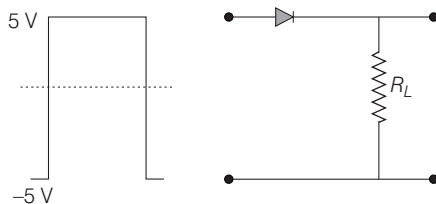
Then, the output signal across R_L will be
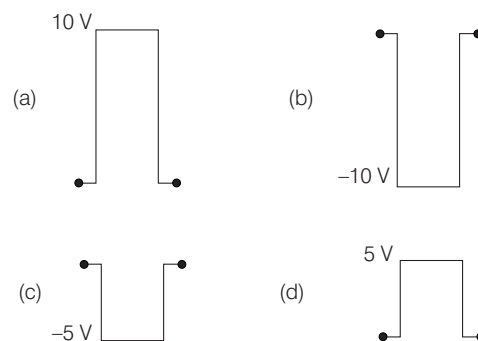
7 To plot forward characteristic of p-n junction diode, the correct circuit diagram is
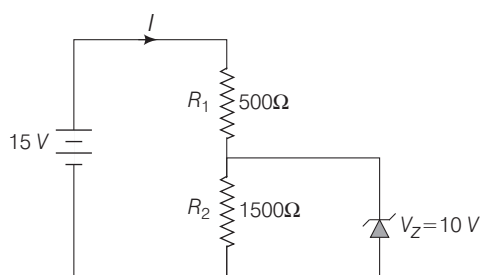
8 A figure is given below

The current through the battery is

(a) 0.5 A   (b) 1 A
(c) 1.5 A   (d) 2 A

9 In the given circuit, the current through the zener diode is

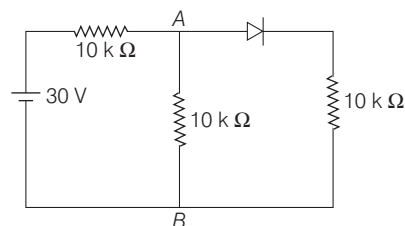(a) 10 mA   (b) 6.67 mA
(c) 5 mA   (d) 3.33 mA

10 The length of germanium rod is 0.928 cm and its area of cross-section is $1\,\text{mm}^2$. If for germanium

$n_i = 2.5 \times 10^{19}\,\text{m}^{-3}$, $\mu_h = 0.19\,\text{m}^2\,\text{V}^{-1}\,\text{s}^{-1}$,
$\mu_e = 0.39\,\text{m}^2\text{V}^{-1}\text{s}^{-1}$, then resistance is

(a) $2.5\,\text{k}\,\Omega$ (b) $4.0\,\text{k}\,\Omega$ (c) $5.0\,\text{k}\,\Omega$ (d) $10.0\,\text{k}\,\Omega$

11 In the figure, potential difference between A and B is

(a) 10 V   (b) 20 V   (c) 30 V   (d) 40 V

12 In a common-base mode of a transistor, the collector current is 5.488 mA for an emitter current of 5.60 mA. The value of the base current amplification factor (β) will be

➙ **AIEEE 2011**

(a) 49   (b) 50   (c) 51   (d) 48

13 For a common emitter configuration, if α and β have their usual meanings, the incorrect relationship between α and β is

➙ **JEE Main 2016 (Offline)**

(a) $\dfrac{1}{\alpha} = \dfrac{1}{\beta} + 1$ (b) $\alpha = \dfrac{\beta}{1-\beta}$ (c) $\alpha = \dfrac{\beta}{1+\beta}$ (d) $\alpha = \dfrac{\beta^2}{1+\beta^2}$

ANSWERS

Hints and Explanations

SESSION 1

1 Based on the theory discussed, we can conclude that when temperature increases, number density of current carriers increases in the semiconductor, relaxation time decreases but effect of relaxation time will be ignored.

2 Carbon, silicon and germanium are semiconductors.

$(E_g)_C = 5.2\,\text{eV}$,
$(E_g)_{\text{Si}} = 1.21\,\text{eV}$
and $(E_g)_{\text{Ge}} = 0.75\,\text{eV}$
Thus, $(E_g)_C > (E_g)_{\text{Si}}$
and $(E_g)_C > (E_g)_{\text{Ge}}$

3 n-type is obtained by doping the Ge or Si with pentavalent atoms. In n-type semiconductor, electrons are majority carriers and holes are minority carriers, hence option (c) is correct.

4 The number of free electrons for conduction is significant only in Si and Ge but small in C, as C is an impurity.

5 If lattice constant of semiconductor is decreased, then E_c and E_v decreases but E_g increases.

6 In an unbiased p-n junction, the diffusion of charge carriers across the junction takes place from higher concentration to lower concentration. Thus, option (c) is correct.

7 In forward biasing more number of electrons enter in n-side from battery thereby increasing the number of donors on the n-side.

8 In a p-n junction in forward bias potential barrier V_B as well as the width of charge depleted region x decreases.

9 The resistivity of a semiconductor decreases with increase in temperature exponentially. Hence, option (c) is correct.

10 When p-n junction is forward biased, it opposes the potential barrier across junction. When is reverse biased, it supports the same.

11 In forward biasing for an ideal diode resistance of diode is zero and whole resistance in the circuit is R. Hence, voltage across R is V.

12 Forward bias is obtained when the negative terminal of the battery is connected to the n-side and the positive terminal to the p-side of the semiconductor. Then, the negative terminal will repel free electrons in the n-section towards the junction and the positive terminal on the p-side will push the holes towards the junction.

13 If V is the voltage across the junction and I is the circuit current, then
$$V + IR = E \quad \text{or} \quad I = \frac{E}{R} - \frac{V}{R} = -\frac{V}{R} + \frac{E}{R}$$
Slope of load line
$$= -\frac{1}{R} = \frac{1}{1000} = 10^{-3}\,\text{AV}^{-1}$$

14 The diode is forward biased, hence the potential barrier decreases and becomes less. Though in both the options (c) and (d). The diode is forward biased but in (d) the barrier width is less.

15 In the given circuit diode D_1 is reverse biased while D_2 is forward biased, so the circuit can be redrawn as
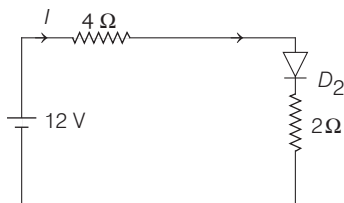
Apply KVL to get current flowing through the circuit
$$-12 + 4I + 2I = 0$$
or $\qquad I = \dfrac{12}{6} = 2\text{A}$

16 For reverse biasing of an ideal diode, the potential of n-side should be higher than potential of p-side. Only option (d) is satisfying the criterion for reverse biasing.

17 For forward biased condition of a p-n junction, p-junction should be at higher potential and n-junction should be at lower potential. So, option (c) is correct.

18 Potential drop in a silicon diode in forward bias is around 0.7 V.
In given circuit, potential drop across $200\,\Omega$ resistor is
$$I = \frac{\Delta V_{\text{net}}}{R} = \frac{3 - 0.7}{200}$$
$\Rightarrow \quad I = 0.0115\text{ A} \quad \Rightarrow \quad I = 11.5\text{ mA}$

19 Given, $f = 50$ Hz and $T = \dfrac{1}{50}$
For full-wave rectifier, $T_1 = \dfrac{T}{2} = \dfrac{1}{100}$
and $f_1 = 100$ Hz

20 Given figure is half wave rectifier as diode conducts only for positive half-cycle. Hence, output waveform is obtained for half cycle only as in figure (c).

21 Zener breakdown in a semiconductor diode occurs when reverse bias exceeds certain value, which is known as breakdown or Zener or Avalanche voltage.

22 For same value of current higher value of voltage is required for higher frequency.

23 Zener diode works in breakdown region.
So, Simple diode $\rightarrow$ (p)
Zener diode $\rightarrow$ (q)
Solar cell $\rightarrow$ (r)
Light dependent resistance $\rightarrow$ (s)

24
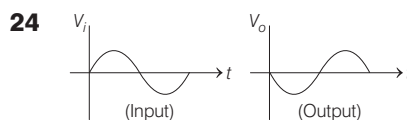
In a CE n-p-n transistor amplifier output is 180° out of phase with input.

25 The condition for a circuit to oscillate are
(i) feedback should be positive
(ii) output voltage feedback $B = \dfrac{1}{A}$

26 $R_f = \dfrac{\Delta V_f}{\Delta I_f} = \dfrac{(2 - 0.5)}{1.5 \times 10^{-3}} = 10^3\ \Omega$
$\qquad = 1\text{ k}\Omega$

27 Zener diodes are specially designed junction diodes, which can operate in the reverse breakdown voltage region

continuously without being damaged. The Zener diode is used as a voltage regulator as constant voltage at variable current under reverse bias is obtained from it.

28 When a junction diode is forward biased energy is released at the junction due to recombination of electrons and holes. In the junction diode made up of gallium arsenide or indium phosphide, the energy is released in visible region. Such a junction diode is called Light Emitting Diode or LED. The radiated energy emitted by LED is equal or less than band gap of semiconductor.

29 When base region has larger width, electron-hole combination increases the base current. The output collector current decreases by the relation, $I_E = I_B + I_C$.

30 The common-emitter transistor amplifier has input resistance equal to 1 kΩ (approx.) and output resistance equal to 10 kΩ (approx.). The output current in CE amplifier is much larger than the input current.

SESSION 2

1 Power gain = Current gain × Voltage gain
$$\text{Current gain} = \beta = \frac{\alpha}{1 - \alpha} = \frac{0.98}{1 - 0.98}$$
$$= 49$$
$$A_V = 49\left(\frac{500 \times 10^3}{R_1}\right)\left[\text{As, } A_v = \beta\frac{R_2}{R_1}\right]$$
Power gain $= 6.0625 \times 10^6$
$$= 49 \times \left(\frac{500 \times 10^3}{R_1}\right) \times 49$$
$$R_1 = 198\ \Omega$$

2 Mobility of electron $(\mu) = \dfrac{\sigma}{ne}$ ...(i)
Resistivity $(\rho) = \dfrac{1}{\sigma}$ ...(ii)
From Eqs. (i) and (ii), we get
$$\mu = \frac{1}{ne\rho} \qquad \text{...(iii)}$$
where, n = number of free electrons per unit volume
$$n = \frac{N_0 \times d}{\text{atomic weight}}$$
$$= \frac{6.023 \times 10^{23} \times 8.96}{63.54}$$
$$= 8.5 \times 10^{22} \qquad \text{...(iv)}$$
From Eqs. (iii) and (iv), we get
$$\mu = \frac{1}{8.5 \times 10^{22} \times 1.6 \times 10^{-19} \times 1.7 \times 10^{-6}}$$
$$= 43.25\,\text{cm}^2/\text{Vs}$$

3 Consider the LED as a point source of light.
Let power of the LED is P.

Intensity at r from the source

$$I = \frac{P}{4\pi r^2} \qquad \text{...(i)}$$

As we know that, $I = \frac{1}{2}\,\varepsilon_0 E_0^2\, c \qquad$ ...(ii)

From Eqs. (i) and (ii), we can write

$$\frac{P}{4\pi r^2} = \frac{1}{2}\,\varepsilon_0 E_0^2\, c$$

or $\; E_0^2 = \dfrac{2\,P}{4\pi\varepsilon_0 r^2 c} = \dfrac{2\times 0.1 \times 9 \times 10^9}{1 \times 3 \times 10^8}$

or $\; E_0^2 = 6 \Rightarrow E_0 = \sqrt{6} = 2.45\,\text{V/m}$

4 Since, no conduction is found when multimeter is connected across P and Q, it means either both P and Q are n-type or p-type. So, it means R is base, when R is connected to common terminal and conduction is seen when other terminal is connected to P or Q. So, it means transistor is n-p-n with R as base.

5 We know that resistance of conductor is directly proportional to temperature (i.e. $R \propto \Delta t$), while resistance of semiconductor is inversely proportional to temperature $\left(\text{i.e. } R \propto \dfrac{1}{\Delta t}\right)$.

Therefore, it is clear that resistance of conductor decreases with decrease in temperature or *vice-versa*, while in case of semiconductor, resistance increases with decrease in temperature or *vice-versa*. Since, copper is pure conductor and germanium is a semiconductor, hence due to decrease in temperature, resistance of conductor decreases while that of semiconductor increases.

6 During – ve cycle, diode will not allow the signal to pass.
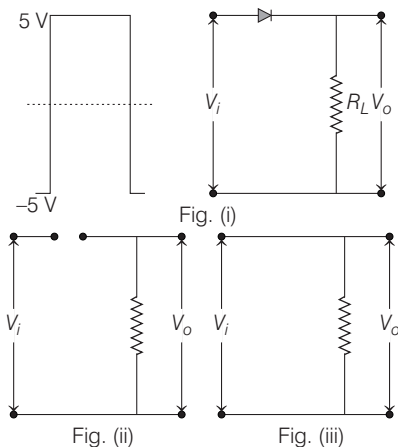
For $V_i < 0$, the diode is reverse biased and hence offer infinite resistance, so circuit would be like as shown in Fig. (ii) and $V_o = 0$.
For $V_i > 0$, the diode is forward biased and circuit would be as shown in Fig. (iii) and $V_o = V_i$.
Hence, the option (d) is correct.

7 For forward bias mode, the p-side of diode has to be at higher potential than n-side. The meters used are DC, so we have to be careful while connecting them w.r.t. polarity.

Last point is to decide the range of meters, the range of meters has to be in such a way that we can have the readings which leads to plot on realistic scale. If we take 0-20 A ammeter, then reading we read from this is tending to 0 to 5 divisions which is not fruitful.

In options (c) and (d), the polarity of ammeter is not correct. Hence, (b) is correct circuit.

8 In the given circuit, diode D_1 is reverse biased, so it will not conduct. Diode D_2 and D_3 are forward biased, so they conduct. The equivalent circuit is as shown below:
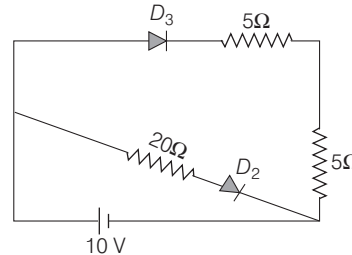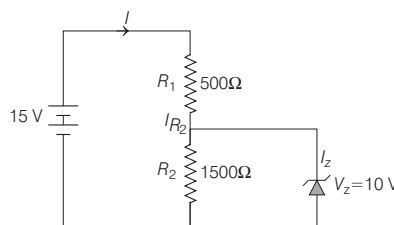

Now, the equivalent resistance of circuit is

$$R_{eq} = \frac{(5+5)\times 20}{(5+5)+20} = \frac{10\times 20}{10+20}$$

$$= \frac{200}{30} = \frac{20}{3}\,\Omega$$

Then, current through the battery,

$$I = \frac{V}{R_{eq}} = \frac{10}{20/3} = \frac{3}{2}$$

$$= 1.5\,\text{A}$$

9 The voltage drop across R_2 is

$$V_{R_2} = V_2 = 10\,\text{V}$$

The current through R_2 is

$$I_{R_2} = \frac{V_{R_2}}{R_2} = \frac{10}{1500}$$

$$= 0.667 \times 10^{-2}\,\text{A}$$

$$= 6.67\,\text{mA}$$

The voltage drop across R_1 is

$$V_{R_1} = 15\,\text{V} - V_{R_2}$$

$$= 15 - 10 = 5\,\text{V}$$

The current through R_1 is

$$I_{R_1} = \frac{V_{R_1}}{R_1} = \frac{5}{500} = 10^{-2}\,\text{A}$$

$$= 10\,\text{mA}$$

The current through the zener diode is

$$I_z = I_{R_1} - I_{R_2} = (10 - 6.67)\,\text{mA}$$

$$= 3.33\,\text{mA}$$

10 $\therefore \; R = \dfrac{\rho l}{A} = \dfrac{L}{n_i e\,(\mu_e + \mu_h)A} \quad \left(\because \rho = \dfrac{1}{\sigma}\right)$

$$= \frac{0.928 \times 10^{-2}}{[2.5 \times 10^{19} \times 1.6 \times 10^{-19}}$$
$$(0.39 + 0.19)\times 10^{-6}]$$

$$= 4000\,\Omega \text{ or } 4\text{ k }\Omega$$

11 For forward biased p-n junction diodes its resistance is zero.
So, net resistance of circuit

$$= 10 + \frac{10 \times 10}{10 + 10} = 15\text{k}\Omega$$

Net current $I = \dfrac{V}{R} = \dfrac{30}{15 \times 10^3}$

$$= 2 \times 10^{-3}\,\text{A}$$

So, potential difference across

$$AB = 2 \times 10^{-3} \times 5 \times 10^3 = 10\text{V}$$

12 $\therefore \; \beta = \dfrac{I_C}{I_B} \quad$ and $\quad I_E = I_C + I_B$

$$\therefore \; \beta = \frac{I_C}{I_E - I_C}$$

$$= \frac{5.488}{5.60 - 5.488} = 49$$

13 As, we know, in case of a common-emitter configuration, DC current gain,

$$\alpha = \frac{I_c}{I_e}.$$

where, I_c is collector current and I_e is emitter current
and AC current gain,

$$\beta = \frac{I_c}{I_b}.$$

where, I_b is base current.
Also, $\quad I_e = I_b + I_c$
Dividing whole equation by I_c, we get

$$\Rightarrow \qquad \frac{I_e}{I_c} = \frac{I_b}{I_c} + 1$$

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

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