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Study of Bipolar Junction transistor (BJT) Characteristics

Research submitted to the Board of Directors of the College of Science as part of the requirements for obtaining a bachelor's degree in the Department of Physics

By

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بسم الله الرحمن الرحيم

{قل امنو به أولا تؤمنوا ان الذين أوتو العلم من قبله اذا يتلى عليهم يخرون للأذقان سجدا}

{ صدق الله العلي العظيم}

الاسراء: ١٠٧

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged.

Signature: ______________________________

Name : **Hussain Fareh Taher**

Date : ______________________________

APPROVAL FOR SUBMISSION

I certify that this project report **“Study of Bipolar Junction transistor (BJT)Characteristics“** was prepared by **Hussain Fareh Taher** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of College of Science Department of Physics – Maysan University

Approved by,

Signature: ____________________________

Supervisor : Muslim Idan Hamil

Date : ____________________________

Dedication

I thank God Almighty first and foremost for the great grace that He has bestowed upon me, then I thank those who favored them. My beloved parents do not cease to me for all their efforts from the moment of my birth to these blessed moments. For everyone who advised me, guided me, contributed, or directed me with me in preparing this research and connecting me to the required references and sources at any of the stages it went through, and I especially thank the distinguished professor: "**Muslim Idan Hamil**", for helping me Supporting me and guiding me with advice, education, correction, and all that he did with me. I am also pleased to thank the esteemed college administration: "Faculty of Science / Physics department**".**

Abstract

The paper includes study of bipolar junction transistor. BJT is a semiconductor device that is constructed with 3 doped semiconductor Regions i.e., Base, Collector & Emitter separated by 2 p-n Junctions. Bipolar transistors are manufactured in two types, PNP and NPN, and are available as separate components, usually in large quantities. The prime use or function of this type of transistor is to amplify current. This makes them useful as switches or amplifiers. They have a wide application in electronic devices like mobile phones, televisions, radio transmitters, and industrial control. Also, small until the current of the collector began to rise.

Contents

Chapter one

Introduction of Semiconductor

(1.1)Introduction of Semiconductors:

Semiconductor electronics is commonplace in all household Semiconductor devices have enabled economically reasonable fiber-based optical communication optical storage, and high-frequency amplification and have recently revolutionized photography, display technology, and lighting. By now solar energy harvesting with photovoltaics contributes a significant portion to the energy mix. Along with these tremendous technological developments, semiconductors have changed the way we work, communicate, entertain, and think. The technological progress of semiconductor materials and devices is evolving continuously with a large worldwide effort in human and monetary capital. For students, semiconductors offer a rich and exciting field with a great tradition, offering diverse fundamental and applied topics (1). Around 1898, Karl Ferdinand Braun invented a type of diode during the development of the radio. He used the rectifying properties of galena crystal (lead sulfide). In 1909, Braun shared the Nobel Prize in physics with Guglielmo Marconi for the development of wireless telegraphy. The historic development of semiconductor physics and technology began in the second half of the 19th century. In 1947, the commercial realization of the transistor was the impetus to a fast- paced development that created the electronics and photonics industries. Products founded on the basis of semiconductor devices such as computers (CPUs, mem- ores), optical-storage media (lasers for CD, DVD), communication infrastructure (lasers and photodetectors for optical-fiber technology, high frequency electronics for mobile communication), displays (thin film transistors, LEDs), projection (laser diodes) and general lighting (LEDs) are commonplace. Thus, fundamental research on semiconductors and semiconductor physics and its offspring in the form of devices has contributed largely to the development of modern civilization and culture(A+H2). Semiconductors have the same type of band structure as an insulator, but the energy gap is much smaller, on the order of 1 eV(2).

The band structure of a semiconductor is shown in Figure Because the Fermi level is located near the middle of the gap for a semiconductor and Eg is small, appreciable numbers of electrons are thermally excited from the valence band to the conduction band. Because of the many empty levels above the thermally filled levels in the conduction band, a small applied potential difference can easily raise the electrons in the conduction band into available energy states, resulting in a moderate current A semiconductor is a material that is between conductors and insulators in its ability to conduct electrical current(3). A semiconductor in its pure (intrinsic) state is neither a good conductor nor a good insulator. Single-element semiconductors are antimony (Sb), arsenic (As), astatine (At), boron (B), polonium (Po), tellurium (Te), silicon Si), and germanium (Ge). Compound semiconductors such as gallium arsenide, indium phosphide, gallium nitride, silicon carbide, and silicon germanium are also commonly used. The single-element semiconductors are characterized by atoms with four valence electrons. Silicon is the most commonly used semiconductor. A semiconductor material is one whose electrical properties lie in between those of insulators and good conductors.

(1.2) Semiconductors types: -

(1.2.1) Intrinsic Semiconductor: -

We shall take the most common case of Ge and Si whose lattice structure is shown in Fig. [1-1].

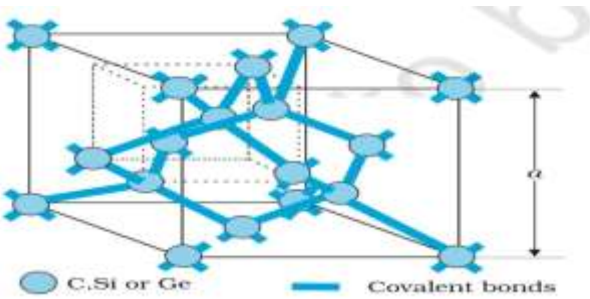

Figure 1 1:Three-dimensional crystal structure for Carbon, Silicon or Germanium.

These structures are called the diamond-like structures. Each atom is surrounded by four nearest neighbors. We know that Si and Ge have four valence electrons. In its crystalline structure, every Si or Ge atom tends to share one of its four valence electrons with each of its four nearest neighbor atoms, and also to take share of one electron from each such neighbor. These shared electron pairs are referred to as forming a covalent bond or simply a valence bond. The two shared electrons can be assumed to shuttle back-and- forth between the associated atoms holding them together strongly.

Figure [1-2] schematically shows the 2-dimensional representation of Si or Ge structure shown in Fig. [1-1] which over emphasizes the covalent bond. It shows an idealized picture in which no bonds are broken (all bonds are intact).

Such a situation arises at low temperatures. As the temperature increases, more thermal energy becomes available to these electrons and some of these electrons may break–away (becoming free electrons contributing to conduction). The thermal energy effectively ionizes only a few atoms in the crystalline lattice and creates a vacancy in the bond as shown in Fig. [1-3(a)]. The neighborhood, from which the free electron (with charge –q) has come out leaves a vacancy with an effective charge (+q).

This vacancy with the effective positive electronic charge is called a hole. The hole behaves as an apparent free particle with effective positive charge In intrinsic semiconductors, the number of free electrons, ne is equal to the number of holes, nh. That is ne = nh = ni, where ni is called intrinsic carrier concentration. Semiconductors possess the unique property in which, apart from electrons, the holes also move. Suppose there is a hole at site 1 as shown in Fig. [1.3(a)]. The movement of holes can be visualized as shown in Fig.[1.3(b)]. An electron from the covalent bond at site 2 may jump to the vacant site 1 (hole). Thus, after such a jump, the hole is at site 2 and the site 1 has now an electron. Therefore, apparently, the hole has moved from site 1 to site 2.

The free electron moves completely independently as conduction electron and gives rise to an electron current, I_e under an applied electric field. Remember that the motion of hole is only a convenient way of describing the actual motion of bound electrons, whenever there is an empty bond anywhere in the crystal. Under the action of an electric field, these holes move towards negative potential giving the hole current,I_h (4).

$$I = I_h + I_e \dots \dots \dots \dots \dots \dots (1)$$

$I = total\ curren.$

$I_{h=}$gaps current.

$Ie = alactrons\ current.$

The total current, I is thus the sum of the electron current I_e and the hole current I_h: It may be noted that apart from the process of generation of conduction electrons and holes, a simultaneous process of recombination occurs in which the electrons recombine with the holes. At equilibrium, the rate of generation is equal to the rate of recombination of charge carriers.

The recombination occurs due to an electron colliding with a hole.

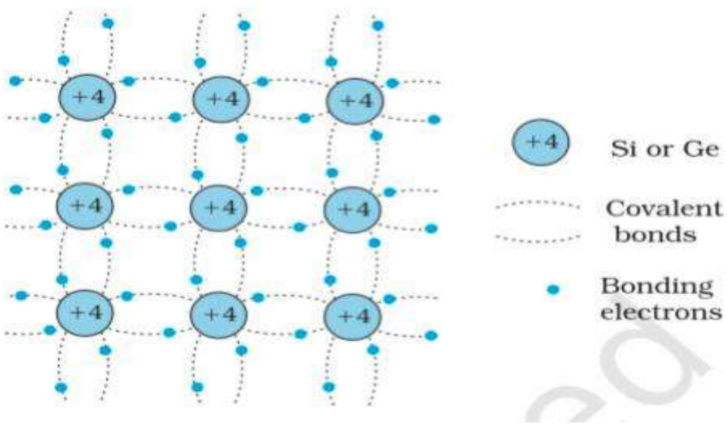

Figure 1 2:Schematic two-dimensional representation of Si or Ge structure showing covalent bonds at low temperature (all bonds intact). +4 symbol indicates inner cores of Si or Ge(5).

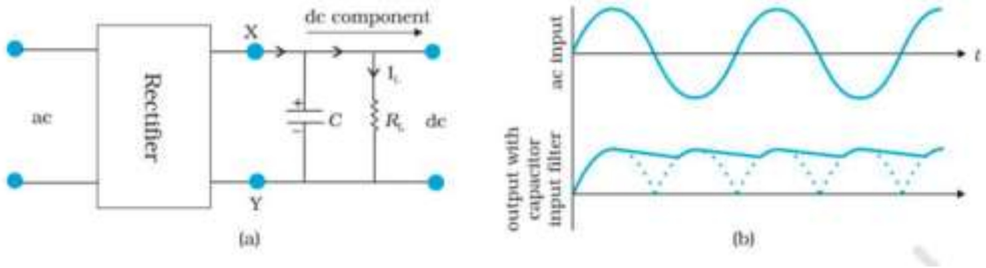

Figure 1 3: (a) Schematic model of generation of hole at site 1 and conduction electron due to thermal energy at moderate temperatures. (b) Simplified representation of possible thermal motion of a hole.

Here, some electrons are shown in the conduction band. These have come from the valence band leaving equal number of holes there (6).

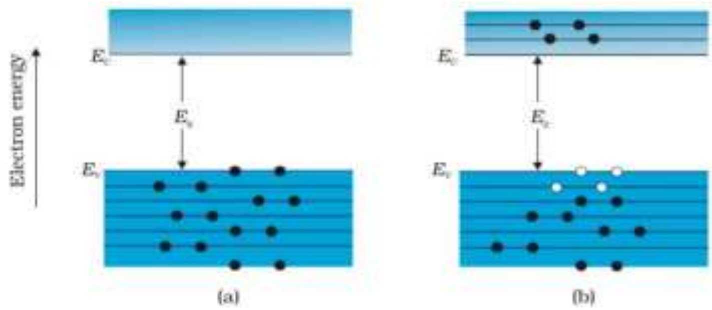

Figure 1 4:An intrinsic semiconductor at T = 0 K behaves like insulator. (a) At T > 0 K, four thermally generated electron-hole pairs. The filled circles represent electrons and empty circles represent holes(b).

(1.2.2) Extrinsic Semiconductor: -

The conductivity of an intrinsic semiconductor depends on its temperature, but at room temperature its conductivity is very low. As such, no important electronic devices can be developed using these semiconductors. Hence there is a necessity of improving their conductivity. This can be done by making use of impurities. When a small amount, say, a few parts per million (ppm), of a suitable impurity is added to the pure semiconductor, the conductivity of the semiconductor is increased manifold (7).

Such materials are known as extrinsic semiconductors or impurity semiconductors. The deliberate addition of a desirable impurity is called doping and the impurity atoms are called dopants. Such a material is also called a doped semiconductor. The dopant has to be such that it does not distort the original pure semiconductor lattice.

It occupies only a very few of the original semiconductor atom sites in the crystal. A necessary condition to attain this is that the sizes of the dopant and the semiconductor atoms should be nearly the same(8) .

There are two types of dopants used in doping the tetravalent Si or Ge: (i) Pentavalent (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc. (ii) Trivalent (valency 3); like Indium (In), Boron (B), Aluminum (Al), etc. We shall now discuss how the doping changes the number of charge carriers (and hence the conductivity) of semiconductors. Si or Ge belongs to the fourth group in the Periodic table and, therefore, we choose the dopant element from nearby fifth or third group, expecting and taking care that the size of the dopant atom is nearly the same as that of Si or Ge (9). Interestingly, the pentavalent and trivalent dopants in Si or Ge give two entirely different types of semiconductors as discussed below.

(1.3) Types Semiconductor:-

There are two types of semiconductor: -

(1.3.1)N-Type Semiconductor:-

To increase the number of conduction-band electrons in intrinsic silicon, pentavalent impurity atoms are added. These are atoms with five valence electrons such as arsenic (As)،(phosphorus (P), bismuth (Bi), and antimony (Sb). each pentavalent atom (antimony, in this case) forms covalent bonds with four adjacent silicon atoms. Four of the antimony atom’s valence electrons are used to form the covalent bonds with silicon atoms, leaving one extra electron. This extra electron becomes a conduction electron because it is not involved in bonding. Because the pentavalent atom gives up an electron, it is often called a donor atom. The number of conduction electrons can be carefully controlled by the number of impurity atoms added to the silicon (10).

A conduction electron created by this doping process does not leave a hole in the valence band because it is in excess of the number required to fill the valence Band. As illustrated in Figure[1-5].

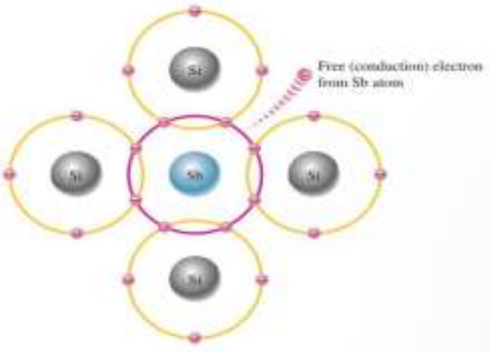

Figure 1 5: Pentavalent impurity atom in a silicon crystal structure.

Majority and Minority Carriers Since most of the current carriers are electrons, silicon or germanium) doped with pentavalent atoms is an n-type semiconductor (the n stands for the negative charge on an electron). The electrons are called the majority carriers in n-type material. Although the majority of current carriers in n-type material are electrons، there are also a few holes that are created when electron-hole pairs are thermally generated. These holes are not produced by the addition of the pentavalent impurity atoms. Holes in an n-type material are called minority carriers. This type of semiconductor is obtained when a pentavalent material like antimony (Sb) is added to pure germanium crystal. As shown in Fig. below, each antimony atom forms covalent bonds with the surrounding four germanium atoms with the help of four of its five electrons. The fifth electron is superfluous and is loosely bound to the antimony atom. Hence, it can be easily excited from the valence band to the conduction band by the application of electric field or increase in thermal energy. It is seen from the above description that in N-type semiconductors, electrons are the majority carriers while holes constitute the minority carriers (11).

(1.3.2)P-Type Semiconductor:-

To increase the number of holes in intrinsic silicon, trivalent impurity atoms are added. These are atoms with three valence electrons such as boron (B), indium (In), and gallium(Ga). As illustrated in Figure [1-6], each trivalent atom (boron, in this case) forms covalent bonds with four adjacent silicon atoms. All three of the boron atom's valence electrons are used in the covalent bonds; and, since four electrons are required, a hole results when each trivalent atom is added. Because the trivalent atom can take an electron, it is often referred to as an acceptor atom. The number of holes can be carefully controlled by the number of trivalent impurity atoms added to the silicon. A hole created by this doping process is not accompanied by a conduction (free) electron(12) .

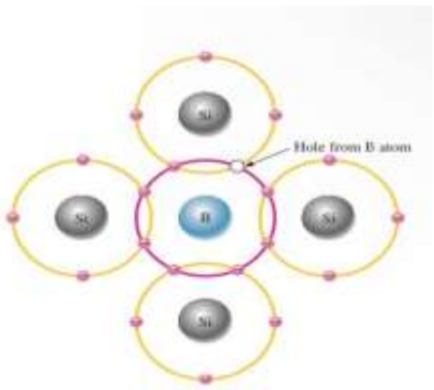

Figure 1٦ :Trivalent impurity atom in a silicon crystal structure. A boron (B) impurity atom is shown in the center (13).

(1.4) Properties of Semiconductors: -

At T = 0 K, all electrons in these materials are in the valence band and no energy is available to excite them across the energy gap.

Therefore, semiconductors are poor conductors at very low temperatures, at higher temperatures, thermal excitation of electrons across the narrow gap is more probable, the conductivity of semiconductors increases rapidly with temperature, Charge carriers in a semiconductor can be negative, positive, or both, when an electron moves from the valence band into the conduction band, it leaves behind a vacant site, called a hole, in the otherwise filled valence band. This hole (electron deficient site) acts as a charge carrier in the sense that a free electron from a nearby site can transfer into the hole, the hole behaves as if it were a particle with a positive charge +e. Semiconductors are the basic materials used in the present solid state (14); -

1-electronic devices like diode, transistor, ICs, etc

. 2- Lattice structure and the atomic structure of constituent elements decide whether a particular material will be insulator, metal or semiconductor.

3- .Metals have low resistivity (10–2 to 10–8 Ωm), insulators have very high resistivity (>108 Ω m–1), while semiconductors have intermediate values of resistivity. 4-Semiconductors are elemental (Si, Ge) as well as compound (GaAs، CdS, etc).

5-Pure semiconductors are called 'intrinsic semiconductors. The presence of charge carriers (electrons and holes) is an 'intrinsic' property of the material and these are obtained as a result of thermal excitation.

6-The number of electrons (ne) is equal to the number of holes (nh) in intrinsic conductors. Holes are essentially electron vacancies with an effective positive charge (15).

7-The number of charge carriers can be changed by 'doping' of a suitable impurity in pure semiconductors. Such semiconductors are known as extrinsic semiconductors. These are of two types (n-type and p-type), In n-type semiconductors, ne >> nh while in p-type semiconductors nh >> ne. 8-n-type semiconducting Si or Ge is obtained by doping with pentavalent atoms (donors) like As, Sb, P, etc., while p-type Si or Ge can be obtained by doping with trivalent atom (acceptors) like B, Al, In etc. 9-ne nh = ni 2 in all cases. Further, the material possesses an overall charge Neutrality (16).

(1.5) Semiconductors Applications: -

From the V-I characteristic of a junction diode we see that it 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. If an alternating voltage is applied across a diode in series with a load, a pulsating voltage will appear across the load only during the half cycles of the ac input during which the diode is forward biased. Such rectifier circuit, as shown in Fig. [1-7], is called a half-wave rectifier. The secondary of a transformer supplies the desired ac voltage across terminals A and B. When the voltage at A is positive, the diode is forward biased and it conducts. When A is negative, the diode is reverse-biased and it does not conduct. The reverse saturation current of a diode is negligible and can be considered equal to zero for practical purposes. (The reverse breakdown voltage of the diode must be sufficiently higher than the peak ac voltage at the secondary of the transformer to protect the diode from reverse breakdown).

Therefore, in the positive half-cycle of ac there is a current through the load resistor RL and we get an output voltage, as shown in Fig. [1-7 (b)](17).

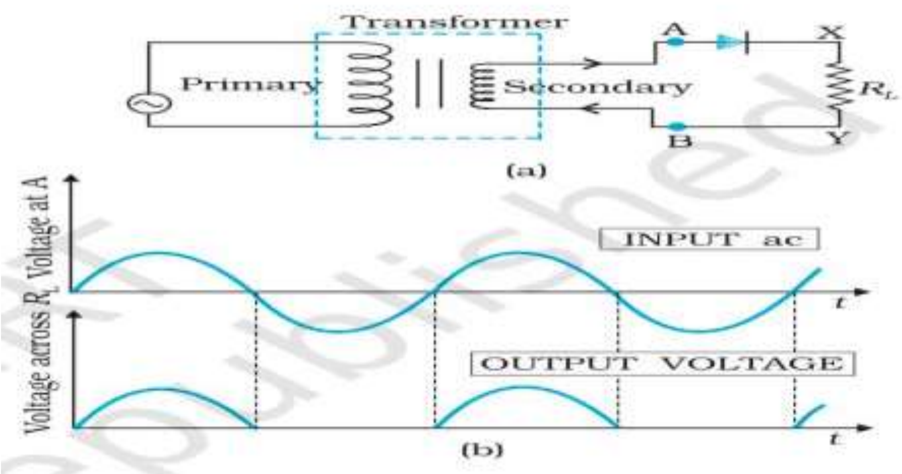

Figure 1 7:(a) Half wave rectifier circuit, (b) Input ac voltage and output voltage waveforms from the rectifier circuit (18).

whereas there is no current in the negative half- cycle. In the next positive half-cycle, again we get the output voltage. Thus, the output voltage, though still varying, is restricted to only one direction and is said to be rectified. Since the rectified output of this circuit is only for half of the input ac wave it is called as half-wave rectifier. The circuit using two diodes, shown in Fig. [1-8(a)], gives output rectified voltage corresponding to both the positive as well as negative half of the ac cycle. Hence, it is known as full-wave rectifier.

Here the p-side of the two diodes are connected to the ends of the secondary of the transformer. The n-side of the diodes are connected together and the output is taken between this common point of diodes and the midpoint of the secondary of the transformer. So, for a full-wave rectifier the secondary of the transformer is provided with a center tapping and so it is called center-tap transformer. As can be seen from Fig.[1-8(b)] the voltage rectified by each diode is only half the total secondary voltage. Each diode rectifies only for half the cycle, but the two do so for alternate cycles. Thus, the output between their common terminals and the center- tap of the transformer becomes a full-wave rectifier output. (Note that there is another circuit of full wave rectifier which does not need a Centre- tap transformer but needs four diodes.) Suppose the input voltage to A with respect to the Centre tap at any instant is positive.

It is clear that, at that instant, voltage at B being out of phase will be negative as shown in Fig.[1-10(b)]. So, diode D1 gets forward biased and conducts (while D2 being reverse biased is not conducting). Hence, during this positive half cycle we get an output current (and an output voltage across the load resistor RL) as shown in Fig.[1-8(c)] (19).

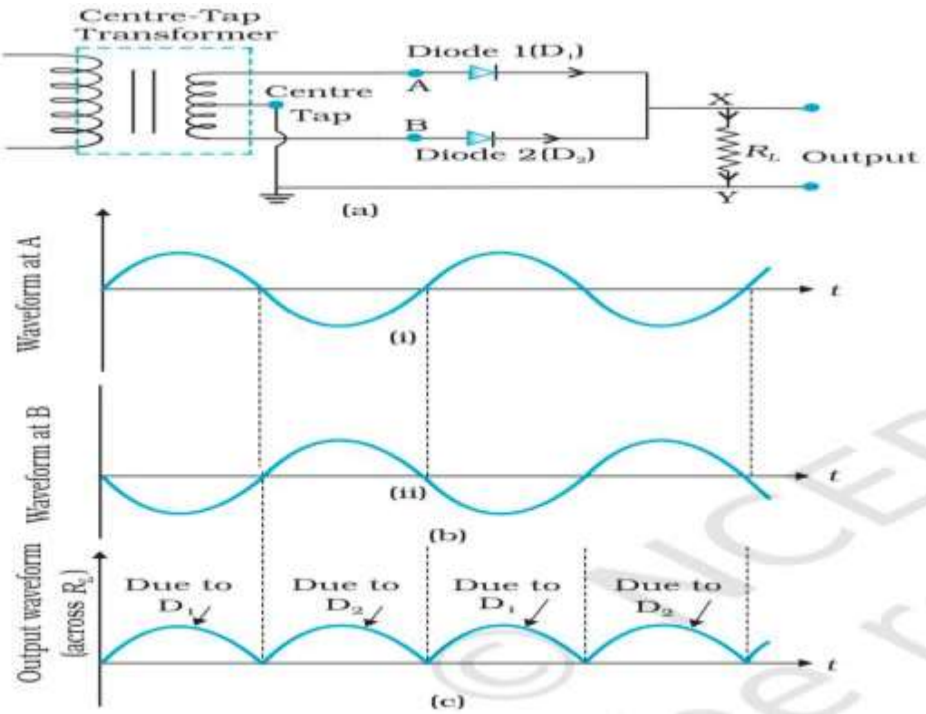

Figure 1 8:(a)(A Full-wave rectifier circuit; (b) Input wave forms given to the diodeD_1 atAandtothediodeD_2 at B; (c) Output waveform across the load RL connected in the full-wave rectifier circuit.

In the course of the ac cycle when the voltage at A becomes negative with respect to Centre tap, the voltage at B would be positive. In this part of the cycle diode D1 would not conduct but diode D2 would, giving an output current and output voltage (across RL) during the negative half cycle of the input ac. Thus, we get output voltage during both the positive as well as the negative half of the cycle. Obviously, this is a more efficient circuit for getting rectified voltage or current than the half- wave rectifier. The rectified voltage is in the form of pulses of the shape of half sinusoids. Though it is unidirectional it does not have a steady value. To get steady dc output from the pulsating voltage normally a capacitor is connected across the output terminals (parallel to the load RL). One can also use an inductor in series with RL for the same purpose. Since these additional circuits appear to filter out the ac ripple and give a pure dc voltage, so they are called filters. Now we shall discuss the role of capacitor in filtering. When the voltage across the capacitor is rising, it gets charged. If there is no external load, it remains charged to the peak voltage of the rectified output. When there is a load, it gets discharged through the load and the voltage across it begins to fall. In the next half-cycle of rectified output it again gets charged to the peak value (Fig.[1-9]. The rate of fall of the voltage across the capacitor depends inversely upon the product of capacitance C and the effective resistance RL used in the circuit and is called the time constant. To make the time constant large value of C should be large. So, capacitor input filters use large capacitors. The output voltage obtained by using capacitor input filter is nearer to the peak voltage of the rectified voltage. This type of filter is most widely used in power supplies (20).

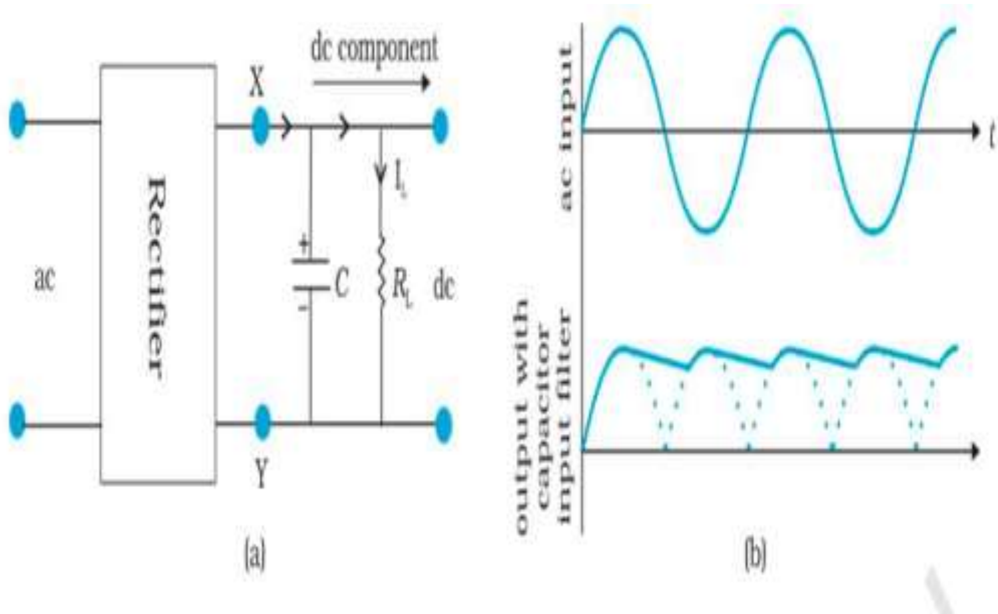

Figure 1 9: (a) A full-wave rectifier with capacitor filter, (b) Input and output voltage of rectifier in (a).

(1.6) Transistor: -

In the mid 1970's a special variety of JEFT invented in Japan called a Static Induction Transistor (SIT) found its way into the power amplifiers produced by Yamaha and Sony. These amplifiers were produced for several years and then discontinued, but are still highly regarded in the high-end audio community SIT devices have a unique characteristic which is of particular value for audio amplifiers. Quoting inventor Nishizawa's patent abstract, “(The) drain-current to drain-voltage characteristic simulates the anode-current to anode-voltage characteristic of the triode vacuum tube very closely.” They have found use in radar and other exotic applications, but after Sony and Yamaha ceased production, versions suitable for audio power amplification have been highly prized and difficult to obtain (21).

Recently there has been renewed interest in SITs, partly because two audio companies have stepped up to the plate and spent the money required to fabricate new devices suitable for audio power amplifiers. The first of these is Digital Do Main in Japan, which has produced two audio amplifiers based on newer versions of original Yamaha Silicon parts. The other is First Watt, which arranged for a production run of a new SIT device using a newer Silicon Carbide process by Semi South(22) .

It is that “triode characteristic” which makes the SIT so special. Your ordinary power JEFT or Mosfet is a voltage variable current source with a set of curves which looks like a Pentode tube:

Basically, the transistor consists of two back-to back P-N junctions manufactured in a single piece of a semiconductor crystal. These two junctions give rise to three regions called emitter, base and collector. junction transistor is simply a sandwich of one type of semiconductor material between two layers of the other type. a layer of N-type material sandwiched between two layers of P-type material (23). Audiophiles often go to great expense to achieve as little as 5 watts of power using Triodes because of their specific sonic character. Unfortunately, triode performance is limited partly by the need to transform the high voltage / low current operation of the triode down to the low voltage / high current domain of loudspeakers. This means a transformer and all the distortion comes with it. Of course, it would be nice if Triodes drove speakers without transformers. It has been a goal of some designers to get transistors to sound like Triodes, with very limited success. Fetes can sound like Pentodes, but it takes a particular set of gyrations to make a Feet do the Triode trick. Then there are those who think nothing less than a glowing bottle will satisfy tube aficionados. Perhaps that is true, but it isn't going to keep me from trying. There are two things we want out of a solid-state device for this purpose. First, we want a "square law" input characteristic like that of tubes. Fortunately, Fetes do that already - the current through the Feet is a good square law function of the Gate to Source voltage. Second, we want a low Drain resistance, equivalent to the Plate impedance of the triode. This is where gain device can be regarded as a variable resistor instead of a variable current source (24).

Why do we want this characteristic? Three reasons: First, it allows a single gain stage with both voltage and current gain, and having a high input impedance and low output impedance without a feedback loop or degeneration. Second, this character allows "working the load-line", the particular description of the path of the gain device through the voltage/current region in the course of amplifying into the loudspeaker. By choosing this line wisely, you can achieve intrinsically lower distortion. Pentodes and Mosfets aren't very good at this. Third like Triodes, SITS have a soft overload characteristic. When over-driven - on peaks they present compressed, rounded waveforms instead of sharp clipping, the result being that they are more graceful under pressure. The entire effort revolves around simplicity and minimalism in circuit design. Certainly, you can get good objective performance with multi-stage circuits and negative feedback. What we want is the sound that can be had from a single gain stage giving both voltage and current gain operated single-ended Class A without feedback or degeneration, and we want it with a high input impedance and a low output impedance. And we want it with reasonably low distortion with a simple low order character. We can try this with Pentodes or Mosfets, but the results don't measure well, and they don't sound as good. This is a clear-cut case where measurements and subjective performance agree. It is worth noting that the original efforts by Sony and Yamaha were not minimalist - they contained many parts in multiple gain stages and used a generous amount of feedback. There are several reasons for the push toward minimalism. The first is simply aesthetic - there is much to admire about an amplifier which performs well with only one transistor. And of course, there is an attractive challenge, which is "How good can you make such an amplifier?". There is another, more practical reason to explore simple circuits. It is generally agreed that if you are going to have distortion, you will want it in a low order harmonic form, kept to only second and third harmonic if possible. A single- ended Class A device is going to generally give you the simplest version of this (25). Transistors are can be configured in three different ways depending on whether the common terminal b/w the input and output ports is base, collector or emitter and are named common base(C_B), common collector(C_C) and common emitter(C_E), accordingly.These can be used as switches or amplifiers based on the choice of OPERATING POINT AND REGION OF OPERATION .For switching the transistor circuits when made to operate between cut-off and saturation regions and for amplifiers when made to operate in their active region It is described as a PNP transistor. an NPN – transistor consisting of a layer of P-type material sandwiched between two layers of N-type material. The emitter, base and collector are provided with terminals which are labelled as E, B and C. The two junctions are: emitter-base (E/B) junction and collector-base (C/B) junction.

The symbols employed for PNP and NPN transistors are also For a PNP transistor, arrowhead points from emitter to base meaning that emitter is positive with respect to base (and also with respect to collector) * For NPN transistor, it points from base to emitter meaning that base (and collector as well) * is positive with respect to the emitter (26).

1. Emitter It is more heavily doped than any of the other regions because its main function is to supply majority charge carries (either electrons or holes) to the base.

2. Base It forms the middle section of the transistor. It is very thin (106 m) as compared to either the emitter or collector and is very lightly-doped.

3. Collector Its main function (as indicated by its name) is to collect majority charge carriers coming from the emitter and passing through the base.

In the Diode tutorials we saw that simple diodes are made up from two pieces of semiconductor material, either silicon or germanium to form a simple PN-junction and we also learnt about their properties and characteristics. If we now join together two individual signal diodes back-to-back, this will give us two PN-junctions connected together in series that share a common P or N terminal. The fusion of these two diodes produces a three-layer, two junction, three terminal device forming the basis of a Bipolar Transistor, or BJT for short. Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics). Then bipolar transistors have the ability to operate within three different regions: Bipolar Transistors are current regulating devices that control the amount of current flowing through them in proportion to the amount of biasing voltage applied to their base terminal acting like a current-controlled switch. The principle of operation of the two transistor types NPN and PNP, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type (27).

(1.7)The aim of the Project: -

Study of Characteristics BJT and input and output of a common base PNP & NPN transistor.

Chapter Two

Introduction of Transistor BJT

(2.1) Bipolar Junction Transistor (BJT) Structure: -

A basic bipolar transistor or BJT are two diodes constructed back-to-back on a piece of silicon. The BJT is constructed with three doped semiconductor regions separated by two PN junctions, the three regions are called emitter, base, and collector. Physical representations of the two types of BJTs. One type consists of two n regions separated by a p region (NPN), and the other type consists of two p regions separated by an n region (NPN). The term bipolar refers to the use of both holes and electrons as current carriers in the transistor structure. This mode of operation is contrasted with unipolar transistors, such as field-effect transistors, in which only one carrier type is employed (electron or hole, ex: diode) .

The transistor was invented by a team of three men at Bell Laboratories in 1947. Although this first transistor was not a bipolar junction device, it was the beginning of a technological revolution that is still continuing. All of the complex electronic devices and systems today are an outgrowth of early developments in semiconductor transistors. Two basic types of transistors are the bipolar junction transistor (BJT) and the field-effect transistor (FET). The BJT is used in two broad areas- as a linear amplifier to amplify an electrical signal and as an electronic switch (28). Signal amplification is important in many applications, such as telecommunications. Before the advent of transistors, signal amplification was accomplished using vacuum tubes. Transistors are much smaller and do not need a long warm-up time needed with vacuum tubes. The invention of the bipolar junction transistor started a revolution which placed electronics on a path of miniaturization; a fact that would have been impossible with vacuum tubes. BJT is a semiconductor device having three regions: Either two are positive and one is negative Or, two are negative and one is positive Named as: Emitter, Base and Collector. Structure: Emitter-Base (E-B) Junction, Collector-Base (B-C) Junction Emitter: Heavily-doped N-type with a moderate size to supply a large number of electrons to the collector through the base. Collector: Less doped N-type with a bigger size than emitter to collect most of electrons injected by the emitter. Base: Very thin lightly-doped P-type semiconductor in between two N-type semiconductors (sandwich) (29).

Emitter: Heavily-doped N-type with a moderate size to supply a large number of electrons to the collector through the base.

Collector: Less doped N-type with a bigger size than emitter to collect most of electrons injected by the emitter.

Base: Very thin lightly-doped P-type semiconductor in between two N-type semiconductors (sandwich).

PNP BJT Emitter: Heavily-doped P-type with a moderate size to supply a large number of holes to the collector through the base.

Collector: Less doped P-type with a larger size than emitter to collect most of holes injected by the emitter.

Base: Very thin lightly-doped N-type semiconductor in between two P-type semiconductors (sandwich)

The bipolar junction transistor or BJT was invented in 1948 at Bell Telephone Laboratories, New Jersey, USA. It was the first mass produced transistor, ahead of the MOS field-effect transistor (MOSFET) by a decade. After the introduction of metal-oxide-semiconductor (MOS) ICs around 1968, the high-density and low-power advantages of the MOS technology steadily eroded the BJT's early dominance. BJTs are still preferred in some high-frequency and analog applications because of their high speed, low noise, and high output power advantages such as in some cell phone amplifier circuits. When they are used, a small number of BJTs are integrated into a high-density complementary MOS (CMOS) chip. Integration of BJT and CMOS is known as the BiCMOS technology. The term bipolar refers to the fact that both electrons and holes are involved in the operation of a BJT. In fact, minority carrier diffusion plays the leading role just as in the PN junction diode. The word junction refers to the fact that PN junctions are critical to the operation of the BJT. BJTs are also simply known as bipolar transistors (30). A BJT is made of a heavily doped emitter (see Fig. 8–1a), a P-type base, and an N-type collector. This device is an NPN BJT. (A PNP BJT would have a P+ emitter, N-type base, and P-type collector.) NPN transistors exhibit higher transconductance.

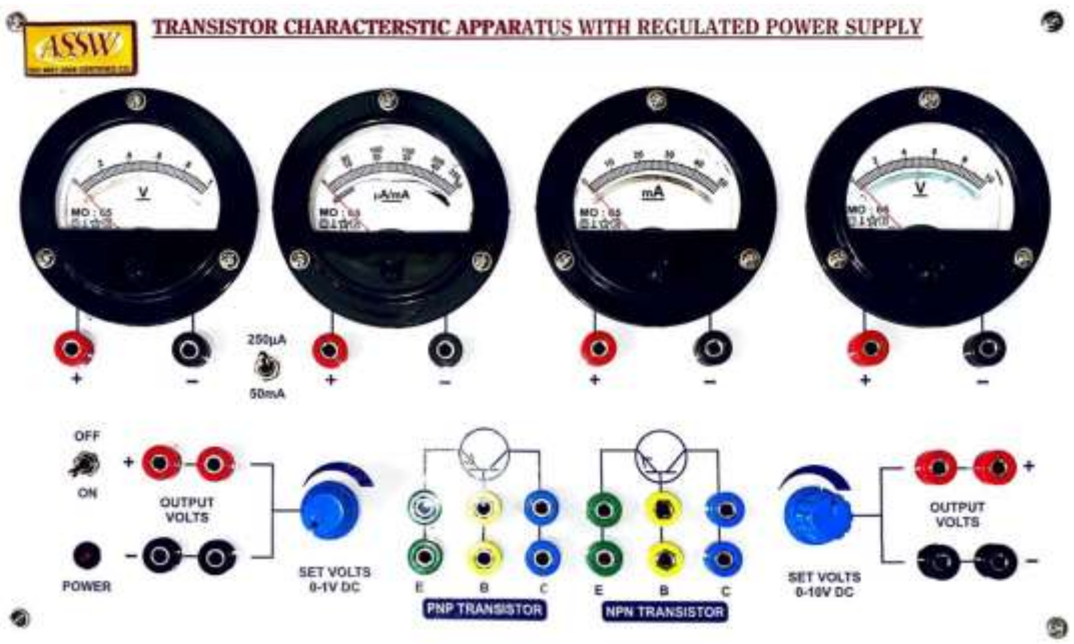

Figure١ .2: Transistor ataractic apparatus with regulated power supply.

(2.2) Device features: -

The device consists of two 0-10VDC/150mA DC regulated power supplies-& 1-0VDC/150mA, four circular meters for measuring voltage and current, one PNP and one NPN The transistor is installed behind the board, and the leads for supplies and transistors are brought in4mm sockets .Catalog number details JE20140 Transistor Characteristics Device.

(2.3) The difference between an NPN and a PNP transistor: -

(2.3.1) NPN transistor

Bipolar transistors have three terminals: base, emitter, and collector. DEVICE FOR REMEMBERING: The arrow on the NPN transistor is Not Pointed. When the battery is attached to the base-emitter junction of the NPN transistor as indicated below, current will flow as the base-emitter junction is in the forward direction (31).

Current does NOT flow is the above circuit. The base-emitter junction is biased in the forward direction HOWEVER, the base-collector junction is in the REVERSE direction so no current flows. Biasing the Base-Emitter Junction Combine the previous two circuits so that base-emitter junction is in the forward direction so for a NPN transistor we would place the battery thus (32).

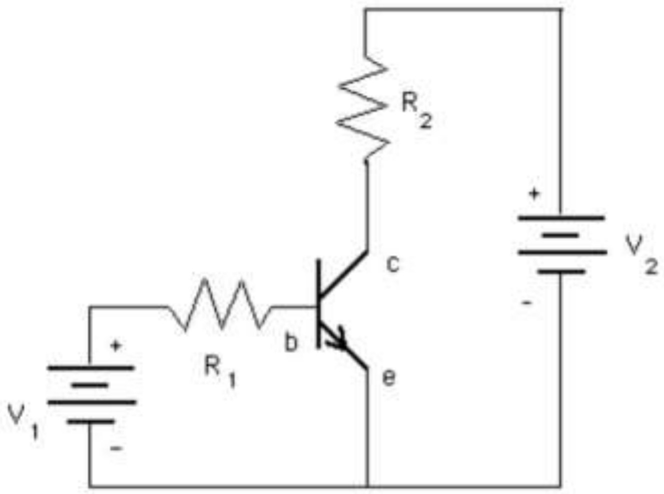

Figure 2.2: Circuit of NPN transistor

The surprising thing about transistors is that when a base current flow (because the base-emitter junction is biased in the forward direction as above) then a collector current will also flow even though the base- collector junction is biased in the reverse direction. Also, the collector current is much larger than the base current.

(2.3.2)PNP Transistor: -

When the two n regions are next to each other (as below) then one has a PNP transistor. It should be clear that one of the diodes in a transistor is in the forward direction emitter-collector while one of the diodes is in the reverse direction (33).

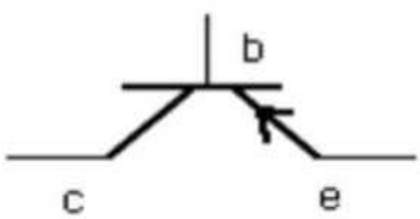

Figure 3.2: Symbol of PNP transistor

So, the direction of the arrow is reverse from the NPN transistor. Transistors like the 2N2222 or PN2907 come in a variety of cases and either metal or plastic. One style is of plastic case or package is indicated below.

Chapter Three

Experiments

(3.1) INTRUDUCTION

In this chapter, we will deal with the practical part through which the practical results of the transistor were obtained.

(3.2) PNP common base configuration

Two terminals are needed for input and two terminals are needed for output, so one terminal is taken as common for both input and output. Based on the terminal which is taken as common there are three types of configurations. They are:-

- **Common base configuration**
- **Common emitter configuration**
- **Common collector configuration**

In common base configuration base terminal taken as common for both input and output. Input is applied between emitter and base terminal and output is taken between collector and base terminal.

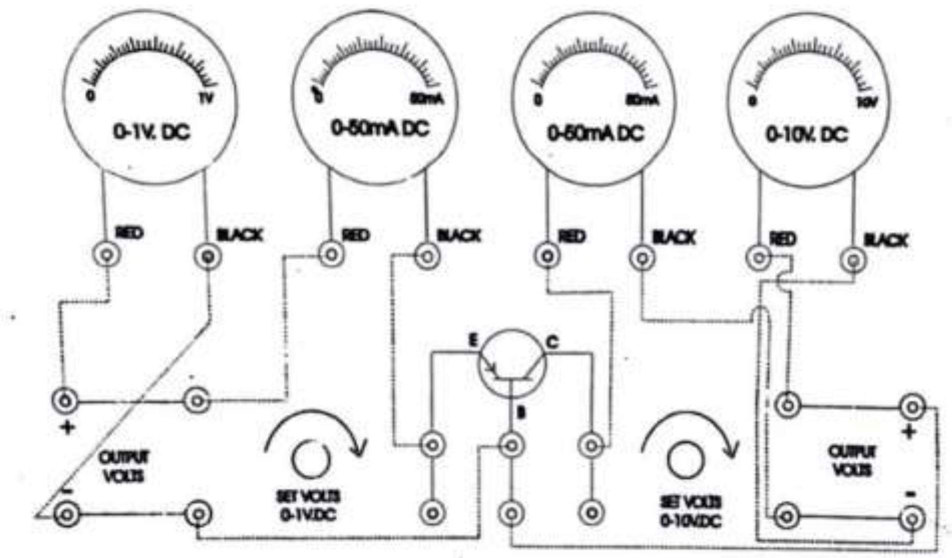

Figure 3 1:PNP common base transistor characteristics apparatus

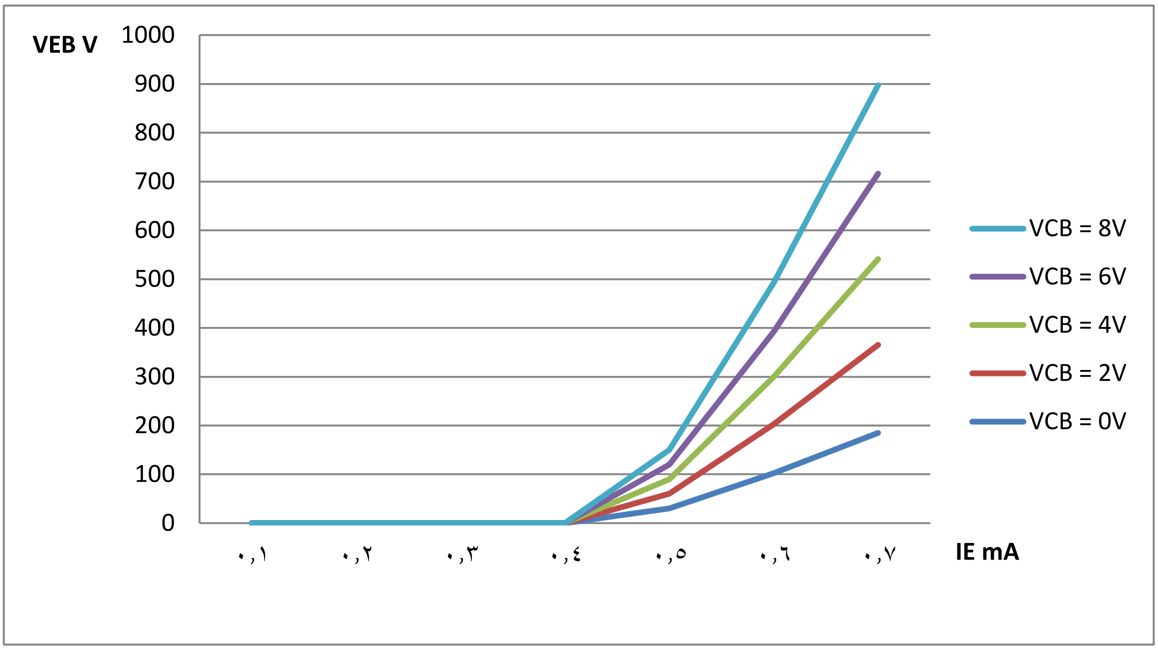

Figure 3 2:input characteristics $V_{EB} - I_E$ for constant V_{CB}.

(3.3) PNP common emitter configuration.

The common-emitter configuration of PNP, the transistor emitter is the terminal common to both the input side and output side. The signal to be amplified is applied between base and emitter forming the input circuit while the amplified output voltage is developed across load impedance in the collector-to-emitter forming the output circuit.

:Table 3 1 Values of current of collector-to-emitter .

accounts	VCB = 0V	VCB = 2V	VCB = 4V	VCB = 6V	VCB = 8V
VEB (V)	**IE (mA)**	**IE (mA)**	**IE (mA)**	**IE (mA)**	**IE (mA)**
0.1	**0**	**0**	**0**	**0**	**0**
0.2	**0**	**0**	**0**	**0**	**0**
0.3	**0**	**0**	**0**	**0**	**0**
0.4	**0**	**0**	**0**	**0**	**0**
0.5	**30**	**30**	**30**	**30**	**30**
0.6	**102.5**	**100**	**97.5**	**92.5**	**100**
0.7	**185**	**180.5**	**175.5**	**175.5**	**180.5**

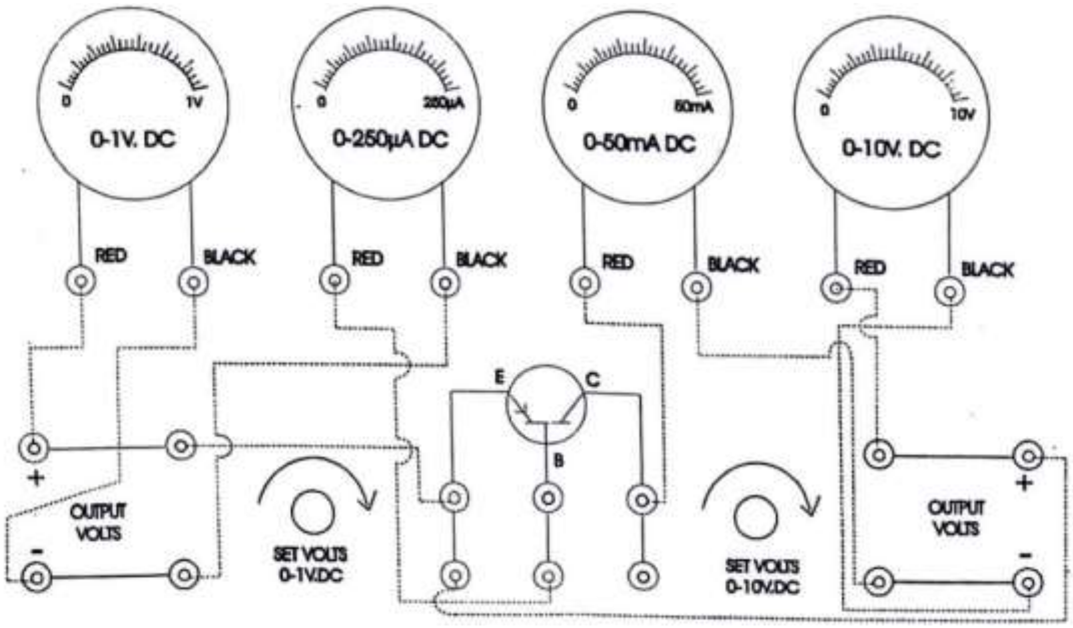

Figure 3 3: NPN common emitter characteristics apparatus.

Table 3 2:For output characteristics V_{CB} - IC for constant I_E .

accounts	IE= 50 µA	IE= 100 µA	IE= 150 µA	IE= 200 µA	IE=250 µA
VCB V	**IC mA**	**IC mA**	**IC mA**	**IC mA**	**IC mA**
0.1	**1.5**	**6.5**	**14**	**22.5**	**33**
0.2	**1.5**	**6.5**	**14.5**	**23**	**33.5**
0.3	**1.5**	**7**	**15**	**24**	**34.5**
0.4	**1.5**	**7**	**15.5**	**25**	**36**
0.5	**1.5**	**7**	**16**	**26.5**	**37**
0.6	**1.5**	**7**	**16.5**	**28**	**39**
0.7	**1.5**	**8**	**17**	**29.5**	**41**
0.8	**1.5**	**8**	**18**	**30.5**	**43**

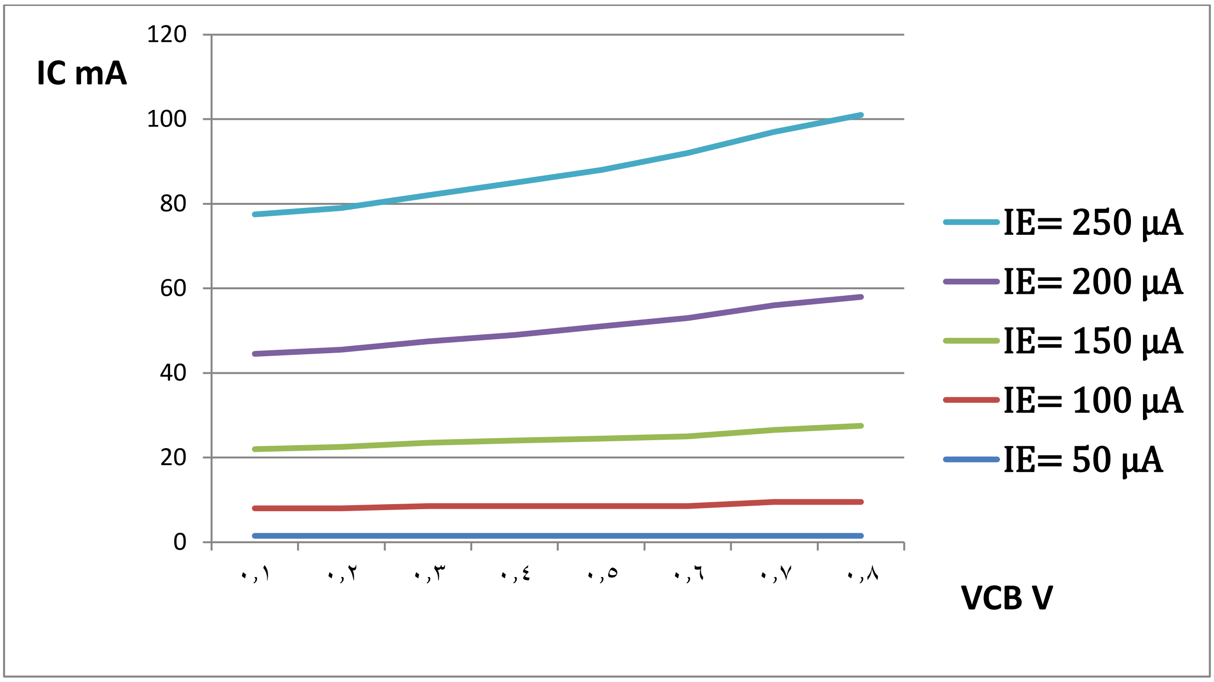

Figure 3 4: Relation between I_C and V_{CB}.

(3.4)NPN common emitter .

Transistor amplifiers amplify an AC input signals that alternates between some positive value and a corresponding negative value. Then some way of "presetting" a common emitter amplifier circuit configuration is required so that the transistor can operate between these two maximum or peak values. This can be achieved using a process known as Biasing. Biasing is very important in amplifier design as it establishes the correct operating point of the transistor amplifier ready to receive signals, thereby reducing any distortion to the output signal.

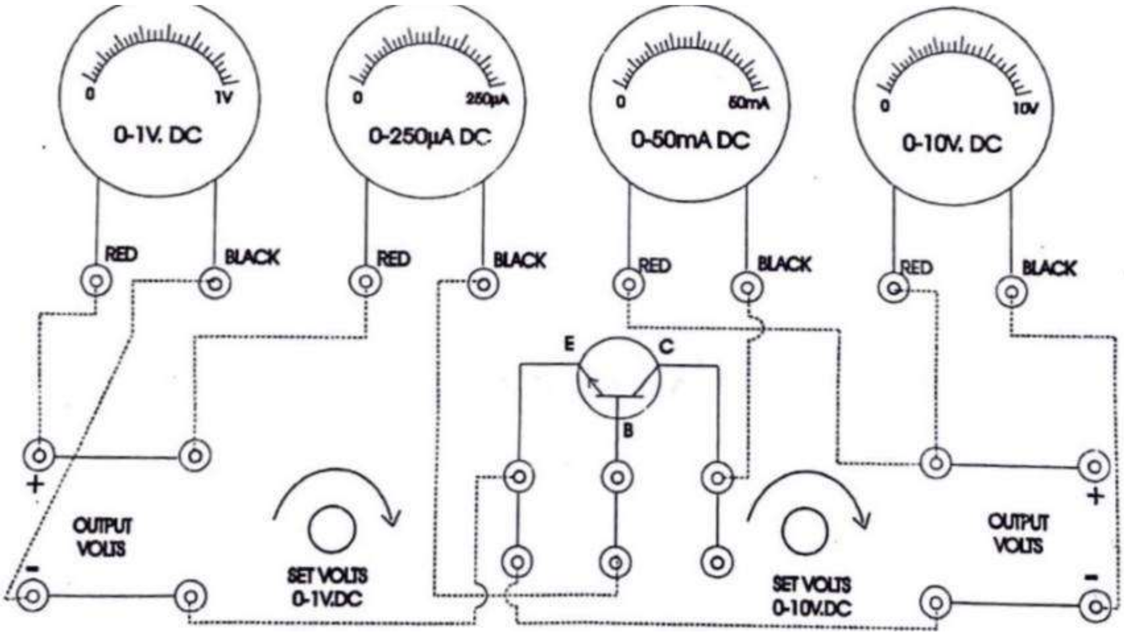

Figure 3 5: NPN common emitter transistor characteristics apparatus.

Table 3 3: For input characteristics $V_{BE} – I_B$ for constant V_{CE}.

accounts	VCE= 0 V	VCE= 2 V	VCE= 4 V	VCE=6 V	VCE= 8 V
VBE V	**IB μA**	**IB μA**	**IB μA**	**IB μA**	**IB μA**
0.1	**0**	**0**	**0**	**0**	**0**
0.2	**0**	**0**	**0**	**0**	**0**
0.3	**0**	**0**	**0**	**0**	**0**
0.4	**0**	**0**	**0**	**0**	**0**
0.5	**12.5**	**0**	**0**	**0**	**0**
0.6	**65**	**10.5**	**10.5**	**15.5**	**25**
0.7	**130.5**	**65**	**65**	**75**	**85**
0.8	**205.5**	**130.5**	**140**	**150**	**155**

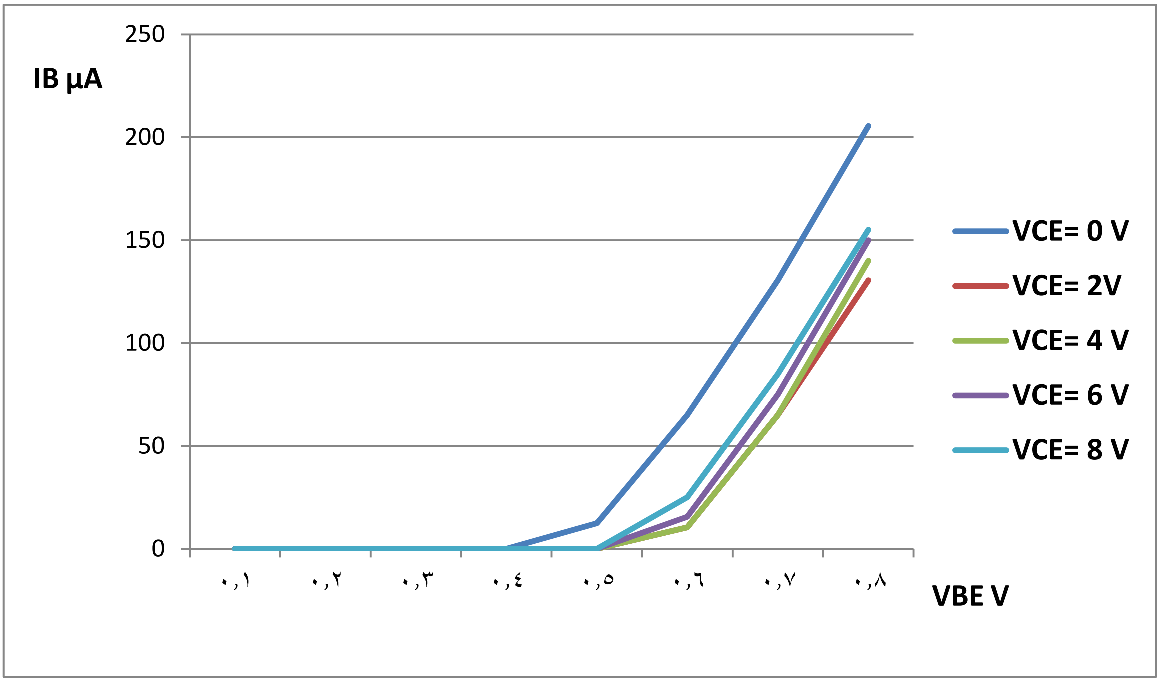

Figure 3 6: Relation between I_B and V_{BE}.

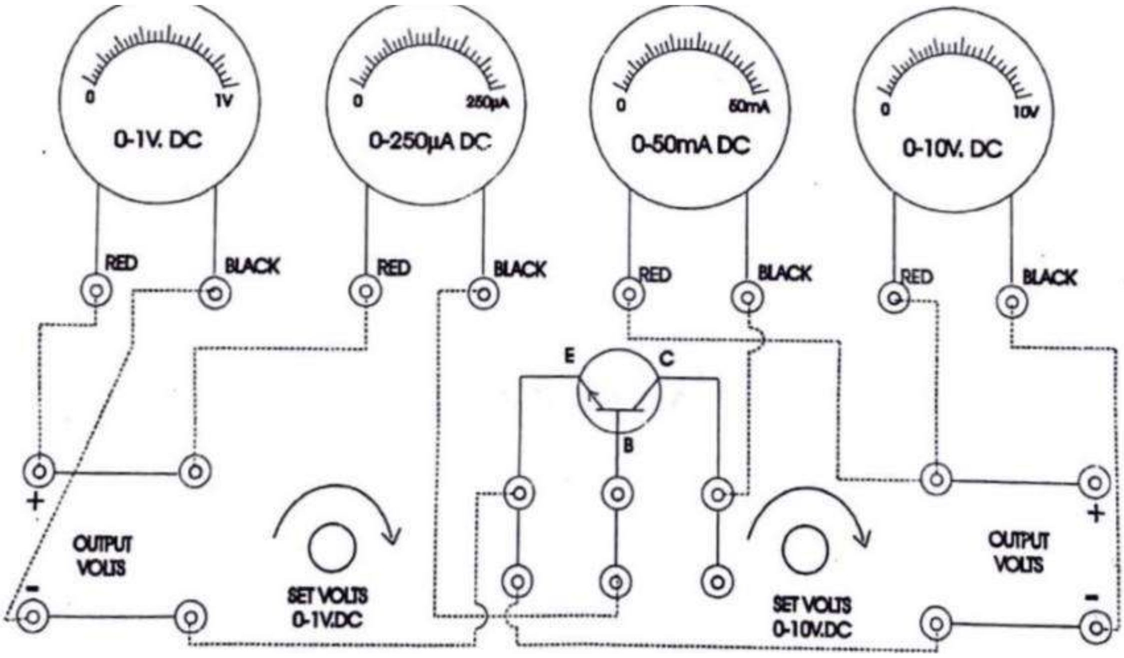

Figure 3 7: NPN common emitter transistor characteristics apparatus.

Table 3 4: For output characteristics $V_{CE} - I_C$ for constant I_B.

accounts	IB= 50 µA	IB= 100 µA	IB= 150 µA	IB= 200 µA	IB= 250 µA
VCE V	**IC mA**	**IC mA**	**IC mA**	**IC mA**	**IC mA**
0.1	**9.5**	**6**	**14**	**21.5**	**33**
0.2	**9.5**	**6**	**14**	**22**	**34**
0.3	**9.5**	**6**	**14.5**	**22**	**35**
0.4	**9.5**	**6**	**14**	**23**	**36**
0.5	**10**	**6**	**15**	**23.5**	**37**
0.6	**10**	**6**	**15.5**	**24**	**38**
0.7	**10**	**6**	**16**	**25**	**39**
0.8	**10**	**6**	**16.5**	**25.5**	**40.5**

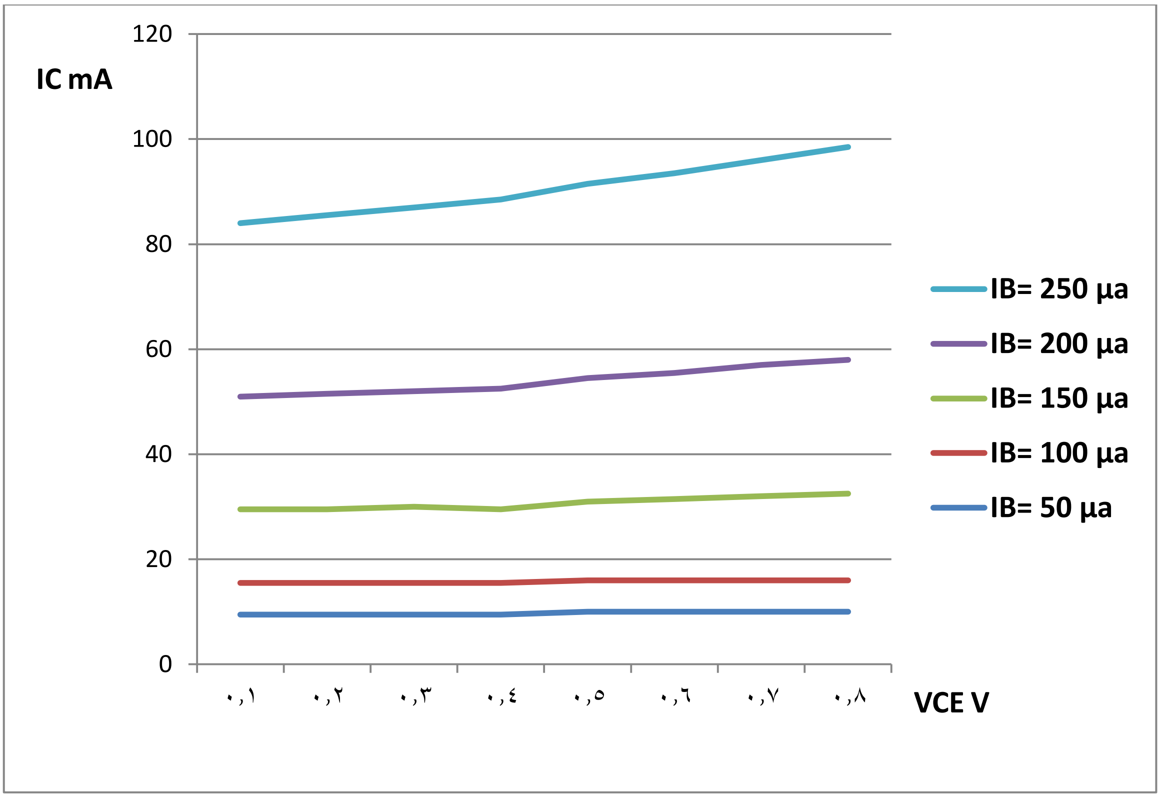

Figure 3 8:Relation between I_C and V_{CE}.

(3.5) Discussion

We have worked on connecting the two types of transistors, which is the NPN link and the NPN link, as shown in the figures in the third chapter, specifically the NPN link. The emitter current values at a specific voltage from 0.1 to 0.4, the current appears to us zero until we reach a certain value of V_{EB}, let it be 0.7, the current begins to rise It is very large, and we have curves in the ascending at the value of V_{EB} 0.5, and the values of the collector current lc appear to us constant at a certain value of the emitter current l_E until we reach a certain value of l_E so the collector current starts to rise, and in connecting NPN also similar that the values of the base current are zero Even to a value of $0.5V_{BE}$, and then its value gradually rises when supplying the values of the V_{BE} and at a specific value of the V_{CE}. Also, in this aspect, the values of lc appeared equal at a certain value of l_B until we reached a certain value of l_B, which is also small, until the collector current began to rise.

(3.6) Reference:

.١ Neamen DA. An introduction to semiconductor devices. 2006.
.٢ Grahn HT. Introduction to semiconductor physics: World Scientific Publishing Company; 1999.
.٣ Brütting W. Introduction to the physics of organic semiconductors. Physics of organic semiconductors. 2005:1-14.
.٤ Snowden CM. Introduction to semiconductor device modelling: World Scientific; 1998.
.٥ Tyagi MS. Introduction to semiconductor materials and devices: John Wiley & Sons; 2008.
.٦ Meng X, Zhang Z. Bismuth-based photocatalytic semiconductors: introduction, challenges and possible approaches. Journal of Molecular Catalysis A: Chemical. 2016;423:533-49.
.٧ King T-C, Yang Y-P, Liou Y-S, Wu C-J. Tunable defect mode in a semiconductor-dielectric photonic crystal containing extrinsic semiconductor defect. solid state communications. 2012;152(24):2189-92.
.٨ Mott N. The metal-insulator transition in extrinsic semiconductors. Advances in Physics. 1972;21(94):785-823.
.٩ Biswal A, Kumar R, Nayak C, Samiappan D. Photonic transmission spectra in an extrinsic semiconductor based Gaussian random multilayer. Optical Materials. 2020;102:109799.
.١٠ Balakrishnan K, Datar A, Oitker R, Chen H, Zuo J, Zang L. Nanobelt self-assembly from an organic n-type semiconductor: propoxyethyl-PTCDI. Journal of the American Chemical Society. 2005;127(30):10496-7.
.١١ Di C-a, Li J, Yu G, Xiao Y, Guo Y, Liu Y, et al. Trifluoromethyltriphenodioxazine: air-stable and high-performance n-type semiconductor. Organic Letters. 2008;10(14):3025-8.
.١٢ Odobel F, Le Pleux L, Pellegrin Y, Blart E. New photovoltaic devices based on the sensitization of p-type semiconductors: challenges and opportunities. Accounts of chemical research. 2010;43(8):1063-71.
.١٣ Zhang N, Sun J, Gong H. Transparent p-type semiconductors: copper-based oxides and oxychalcogenides. Coatings. 2019;9(2):137.
.١٤ Bube RH. Photoelectronic properties of semiconductors: Cambridge University Press; 1992.
.١٥ Adachi S. Handbook on physical properties of semiconductors: Springer Science & Business Media; 2004.
.١٦ Cohen ML, Chelikowsky JR. Electronic structure and optical properties of semiconductors: Springer Science & Business Media; 2012.
.١٧ Shen S-G. Calculation of the elastic properties of semiconductors. Journal of Physics: Condensed Matter. 1994;6(42):8733.
.١٨ Amirtharaj PM, Seiler DG. Optical properties of semiconductors. Handbook of optics. 1995;2:36.1-.96.
.١٩ Haug H, Koch SW. Quantum theory of the optical and electronic properties of semiconductors: World Scientific Publishing Company; 2009.
.٢٠ Bass FG, Bulgakov AA, Tetervov AP. High-frequency properties of semiconductors with superlattices. Moscow Izdatel Nauka. 1989.
.٢١ Riordan M, Hoddeson L, Herring C. The invention of the transistor. Reviews of Modern Physics. 1999;71(2):S336.
.٢٢ Kastner MA. The single-electron transistor. Reviews of modern physics. 1992;64(3):849.
.٢٣ Wong H-S. Beyond the conventional transistor. IBM Journal of Research and Development. 2002;46(2.3):133-68.

.٢٤ Ross IM. The invention of the transistor. Proceedings of the IEEE.٢٨-٧:(١)٨٦؛١٩٩٨ .
.٢٥ Khan AI, Keshavarzi A, Datta S. The future of ferroelectric field-effect transistor technology. Nature Electronics. 2020;3(10):588-97.
.٢٦ Bardeen J, Brattain WH. The transistor, a semi-conductor triode. Physical Review. 1948;74(2):23.٠
.٢٧ Dacey GC, Ross I. The field effect transistor. Bell System Technical Journal. 1955;34(6):1149-89.
.٢٨ Santos LA. An overview on bipolar junction transistor as a sensor for X-ray beams used in medical diagnosis. Sensors. 2022;22(5):1923.
.٢٩ Titus JL, Johnson GH, Schrimpf RD, Galloway KF. Single-event burnout of power bipolar junction transistors. IEEE transactions on nuclear science. 1991;38(6):1315-22.
.٣٠ Dastgeer G, Shahzad ZM, Chae H, Kim YH, Ko BM, Eom J. Bipolar junction transistor exhibiting excellent output characteristics with a prompt response against the selective protein. Advanced Functional Materials. 2022;32(38):2204781.
.٣١ Heimeier HH. A two-dimensional numerical analysis of a silicon npn transistor. IEEE Transactions on Electron Devices. 1973;20(8):708-14.
.٣٢ Wallace RL, Pietenpol WJ. Some circuit properties and applications of npn transistors. Proceedings of the IRE. 1951;39(7):753-67.
.٣٣ Pertijs MA, Meijer GC, Huijsing JH. Precision temperature measurement using CMOS substrate PNP transistors. IEEE Sensors Journal. 2004;4(3):294-300.