

Unit 18

ELECTRONICS

How electrons and holes take part in flow of current through semiconductor diodes?

STUDENT LEARNING OUTCOMES



The students will:

- ✓ [SLO: P-10-E-45] Describe the working of a diode.
- ✓ [SLO: P-10-E-46] Describe the action of a light-emitting diode in passing current in one direction only and emitting light.
- ✓ [SLO: P-10-E-47] Describe and explain the action of relays in switching circuits.
- ✓ [SLO: P-10-E-63] Explain that electronic devices are built from digital logic circuits.
- ✓ [SLO: P-10-E-64] Explain that Boolean logic is the basis for converting analogue data to digital data.
- ✓ [SLO: P-10-E-65] State in words and in truth table form, the action of logic gates.
- ✓ [SLO: P-10-E-66] Identify the use of logic gates for security purposes.
- ✓ [SLO: P-10-E-67] Use circuit symbols for the logic gates.
- ✓ [SLO: P-10-E-68] Identify in given problems how Boolean switches can be put into combinations that then allow them to achieve logical operations.
- ✓ [SLO: P-10-E-69] Describe the action of a bipolar npn transistor as a switch.
- ✓ [SLO: P-10-E-70] Explain that transistors are commonly used in digital devices because they are both economical and act as rapid-response switches.
- ✓ [SLO: P-10-E-71] State that circuits that maintain their 'state' after receiving an input can be said to exhibit 'memory'.
- ✓ [SLO: P-10-E-72] State that quantum computers are still in early stages of development, and have to overcome manufacturing challenges such as core components only functioning at very cold temperatures that are at almost absolute zero.
- ✓ [SLO: P-10-E-73] Compare analogue and digital electronics.

Electronics studies and applies the principles of physics to design, create, and operate active devices such as diodes, transistors and integrated circuits (ICs). These electronic devices control and amplify the flow of electric current and to convert it from one form to another, such as from AC to DC or from analog signals to digital signals.

Electronic devices are playing a major role in modern civilization. The various electronic devices we use in everyday life include computers, mobile phones, automated teller machine (ATM), pen drive, television and digital camera etc. Electronic devices have hugely influenced the development of many aspects of modern society, such as telecommunications, education, health care, industry, security and entertainment. *The branch of physics that helps to study the emission and behaviour of electrons with electronic devices is known as electronics.*

The main component behind the advancement of electronics is the semiconductor industry. The semiconductor industry became one of the largest and most profitable sectors in the global economy. This unit increases student's understanding of the applications and uses of physics in modern technology.

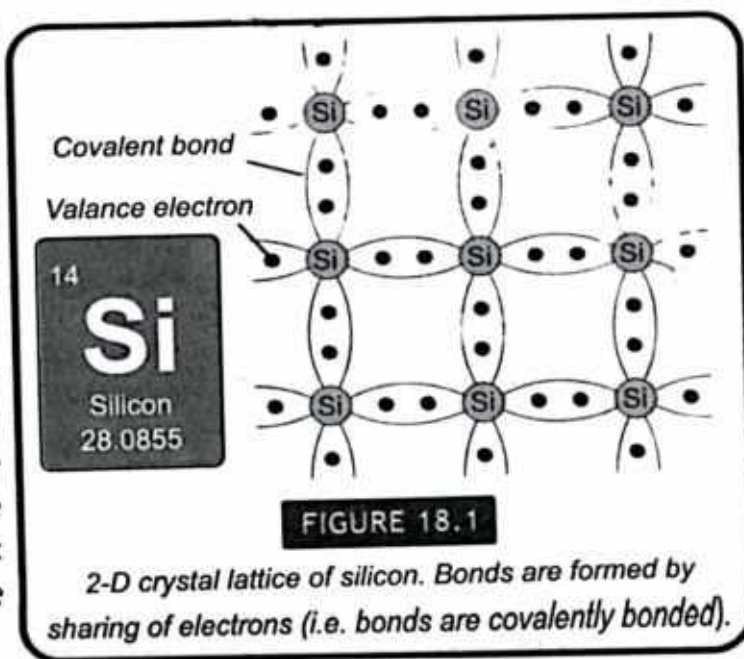
18.1 SEMICONDUCTORS

Materials whose electrical conductivity falls between conductors and insulators are called semiconductors. Atoms of group IV-A of periodic table are semiconductors.

Silicon is a semiconductor material. Atoms in pure silicon contain four electrons in outer orbit. In the crystal lattice structure of Si, the valence electrons of every Si atom are locked up in covalent bonds with the valence electrons of four neighboring Si atoms, as shown in figure 18.1. In pure

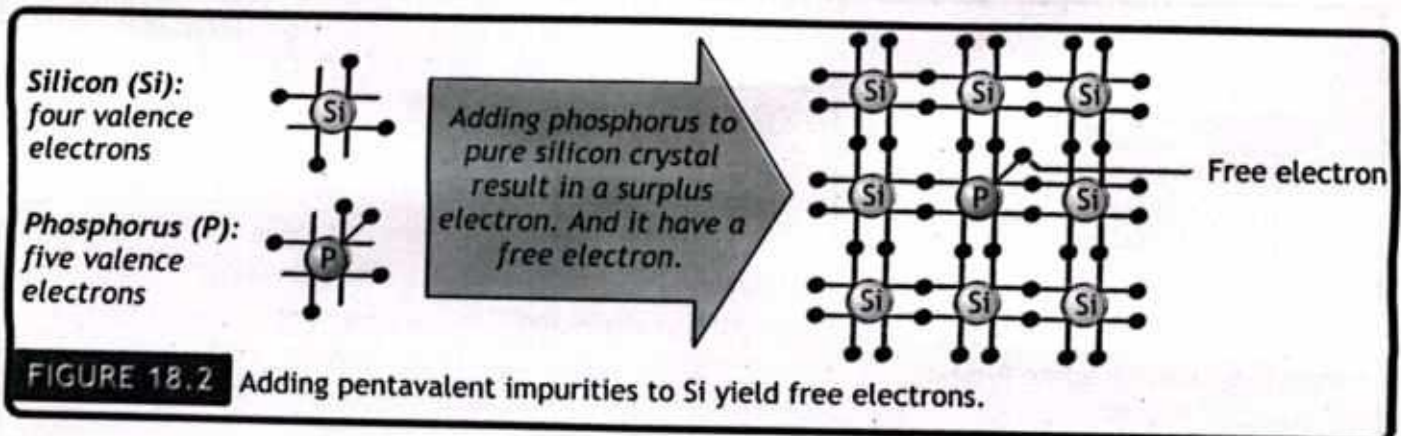
form, Si wafer does not contain any free charge carriers. Such types of pure semiconductors are called intrinsic semiconductors.

In order to make useful semiconductor devices, materials such as phosphorus (P) and aluminium (Al) are added to Si. Those semiconductors that are doped with some specific impurities are called extrinsic semiconductors. These impurities modify the electrical properties of the semiconductor and make it more suitable for electronic conductivity. The extrinsic semiconductors are of two types; p-type and n-type.

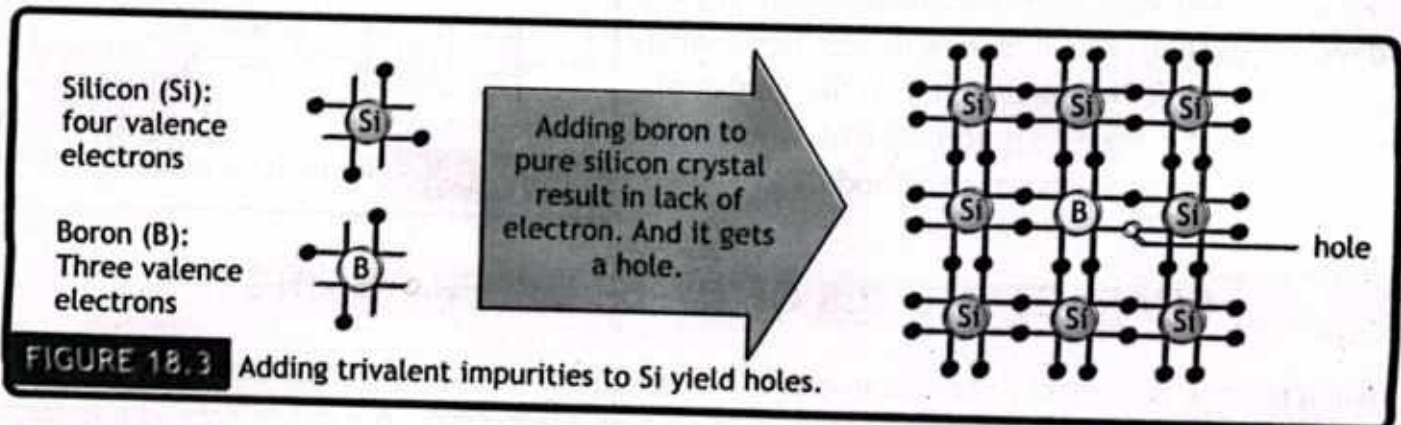


18.2 N-TYPE & P-TYPE SEMICONDUCTORS

When a pentavalent impurity (group V-A elements) such as phosphorus is added to Si, the resulting mixture is called N-type. Four valence electrons of every phosphorus atom are locked up in covalent bond with valence electrons of four neighboring Si atoms. However, the 5th valence electron of phosphorus atom does not find a binding electron and thus remains free to float in the material, as shown in figure 18.2.



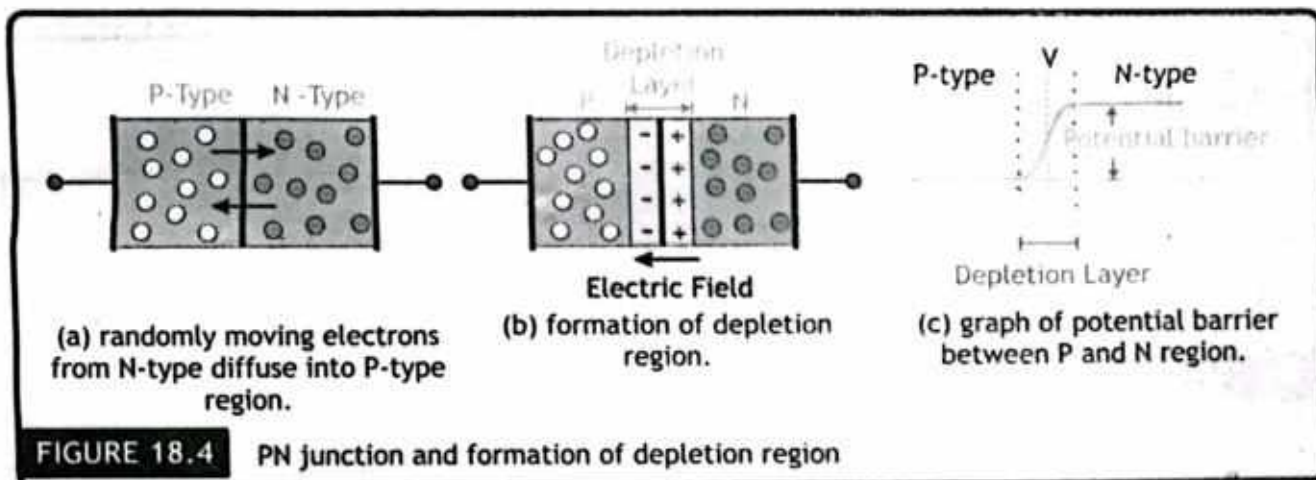
When trivalent impurities (group III-A elements) such as boron is added to Si, the resulting mixture is called P-type. Three valence electrons of every boron atom are locked up in covalent bond with valence electrons of three neighboring Si atoms. However, the fourth electron of the Si atom remains unpaired. A vacant spot "hole" is created within the covalent bond between one boron atom and a neighboring Si atom, as shown in figure 18.3. These holes are considered to be positive charge carriers



18.3 PN JUNCTION (OR DIODE)

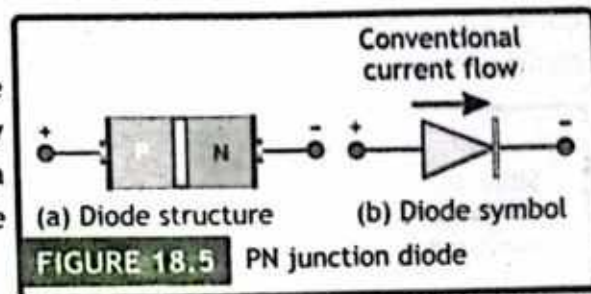
When a crystal of semiconductor is grown in such a way that it's one half is doped with trivalent impurity (p-type) and other half is doped with pentavalent impurity (n-type), then a junction is formed between the two regions. Such a grown crystal is called PN junction. At the junction

between the two regions, randomly moving electrons from N-type diffuse into P-type region and hence fill the vacancies in P-type, as shown in figure 18.4 (a). As a result of this diffusion, negative and positive ions are formed near the junction as shown in figure 18.4 (b). These ions create an electric field directed from N-type to P-type region. It is called depletion region. Thus, a potential barrier is formed at the junction. The value of potential barrier for Ge crystal is 0.3 V and for Si crystal is 0.7 V.



The depletion region is free of mobile charges. The width of depletion layer depends upon carrier concentration. Depletion region stops further diffusion of electrons and holes and maintains the separation of charge carriers.

PN junction diode allows current to pass in only one direction so that's why it is used as rectifier in many electric circuits. The vertical line in the symbol of a diode shows the n-region (figure 18.5 b), whereas the arrow head represents p region of diode.



18.4 CHARACTERISTICS OF DIODE UNDER BIASING

When a diode is connected across an electric supply (potential difference), then it is said to be under biasing. A diode allows current flow in only one direction, so a diode acts as a perfect insulator for currents flowing in one direction and as a perfect conductor for currents flowing through it in the other direction. The biasing in which the diode allows current to flow is called the forward bias and that in which current is resisted is called reverse bias.

18.4.1 FORWARD BIASED

When the positive terminal of a DC source is connected to p-type and negative terminal is connected to n-type semiconductor of a pn junction as shown in 18.6 (a), the junction is said to be in forward biased.

In this circuit, the holes on the P-side being positively charged particles are repelled from the positive bias terminal and driven towards the junction. Similarly, the electrons on the N-side are repelled from the negative bias terminal and driven towards the junction. The result is that the depletion region is reduced in width and the barrier potential is also reduced. Once the potential barrier is reduced by the forward voltage, a conducting path is established for flow of current. The electrons and holes combine causing the current to pass through the junction. This current is called forward current and it is of the order of a few milliamperes (mA). The variation of forward current through the pn junction with the biasing voltage can be studied with the help of the circuit shown in the figure 18.6 (b).

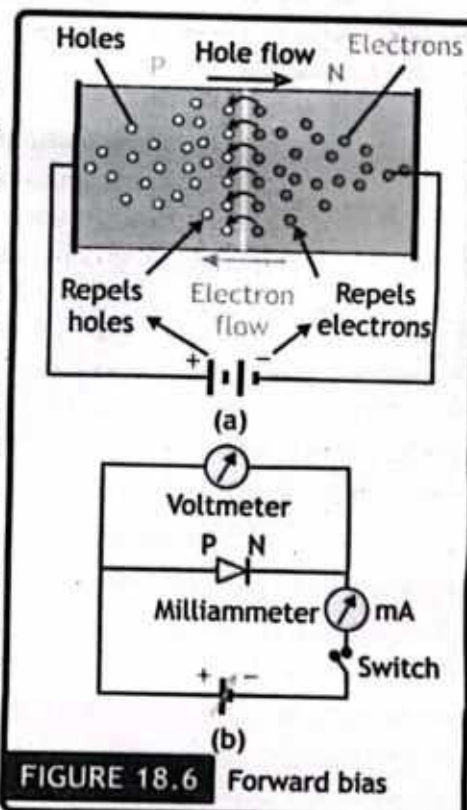


FIGURE 18.6 Forward bias

18.4.2 REVERSED BIASED

When potential at anode (p-type) is smaller than the potential at cathode (n-type), the diode is said to be reverse biased as shown in figure 18.7 (a). In a reverse-biased diode current is blocked.

In a reverse-biased connection, holes in the n-side are forced to the left while electrons in the p-side are forced to the right. This results in an empty zone around the pn-junction that is free of charge carriers creating a wider depletion region. This depletion region acts as an insulator as no current flows through the junction due to majority charge carriers. Only a small current of the order of few microamperes (μA) flows due to minority charge carriers. This small current is known as reverse or leakage current.

The variation of reverse current through the pn-junction with the biasing voltage can be studied with the help of the circuit shown in the figure 18.7 (b).

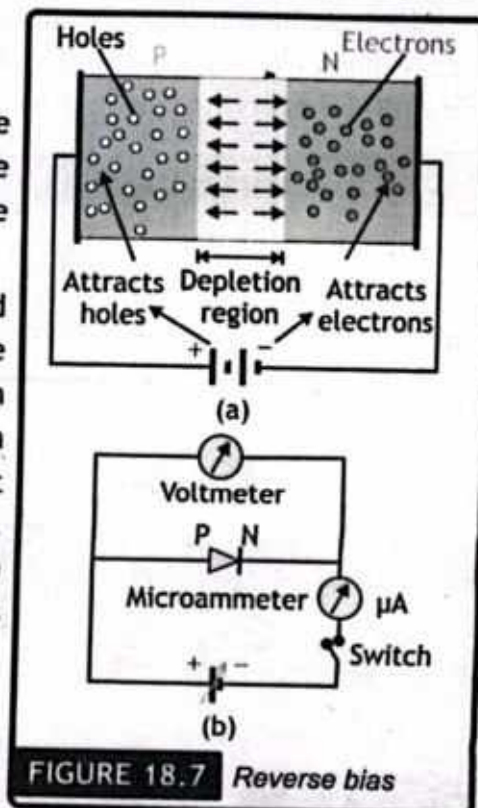
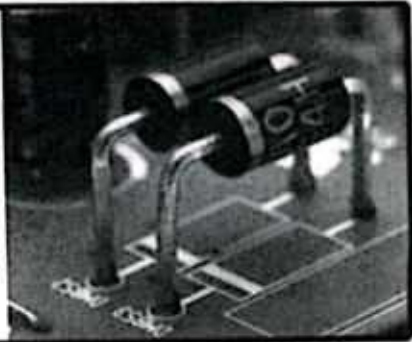


FIGURE 18.7 Reverse bias

UNIT
OPENER?

How electrons and holes take part in flow of current through semiconductor diodes?

In semiconductors current is caused by both electrons and holes. If an external electric field is applied to the semiconductor, the electrons and holes move in opposite directions. Hence they both contribute to the flow of current through semiconductor material.



The current (I) versus voltage (V) graph for a pn junction is shown in figure 18.8. It can be seen that, in the forward bias region, current and voltage are positive. When the forward voltage is less than ' V_o ', the forward current is nearly zero so the diode does not conduct. When the forward voltage is equal to ' V_o ' the diode starts to conduct. In the reverse bias region, current and voltage are negative. As reverse bias voltage is raised, depletion region width increases and a point comes when junction breaks down. This results in large flow of current.

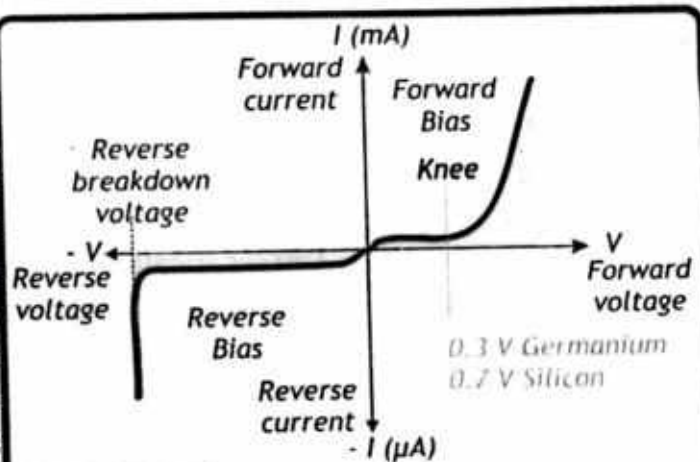


FIGURE 18.8 I-V curve for a semiconductor diode.

18.5 LIGHT-EMITTING DIODE (LED)

Light-Emitting Diode emits energy in the form light and hence they glow when the electric current passes through it. These diodes are made from gallium arsenide phosphide (GaAsP) and gallium phosphide (GaP). The picture and symbol of LED is shown in figure 18.9 (a) and 18.9 (b).

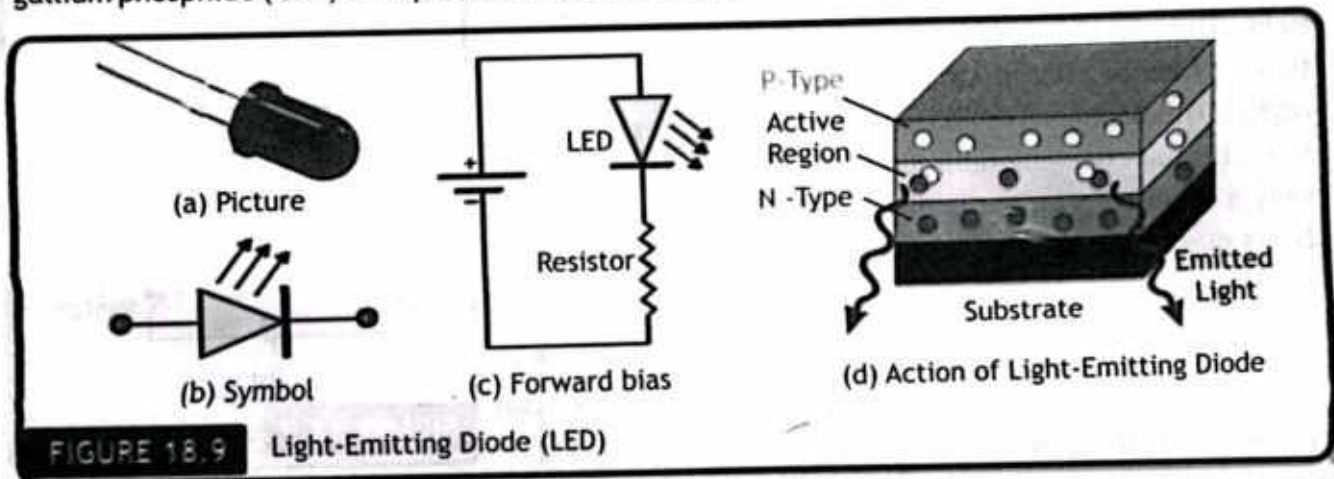


FIGURE 18.9 Light-Emitting Diode (LED)

When the LED is forward biased as shown in figure 18.9 (c), the potential barrier is lowered. The conduction band free electrons from n-region cross the barrier and enter the p-region. As these electrons enter the p-region, they fall into the holes lying in the valence band. Hence, they fall from a higher level to a lower energy level. In the process, they radiate energy as shown in figure 18.9 (d).

A LED is enclosed with a transparent cover to view the emitted light. LEDs can emit light of different colours such as red, green and blue etc. LEDs are widely used in decorative lamps, optical communication and display devices.

18.6 TRANSISTOR

A transistor is a device composed of semi-conductor material that can both conduct and insulate (e.g. germanium and silicon). Transistors switch and modulate electronic current. The transistor was the first device designed to act as both a transmitter, converting sound waves into electronic waves, and resistor, controlling electronic current. The name transistor comes from the 'trans' of transmitter and 'sistor' of resistor. These words describe the operation of a transistor which is the transfer of an input signal from a low resistance circuit to a high resistance circuit.

DO YOU KNOW?

Transistor is a bi-polar device, bipolar refers to the fact that both holes and electrons participate in the conduction process. If only one carrier is employed (electron or hole), it is considered a unipolar device.

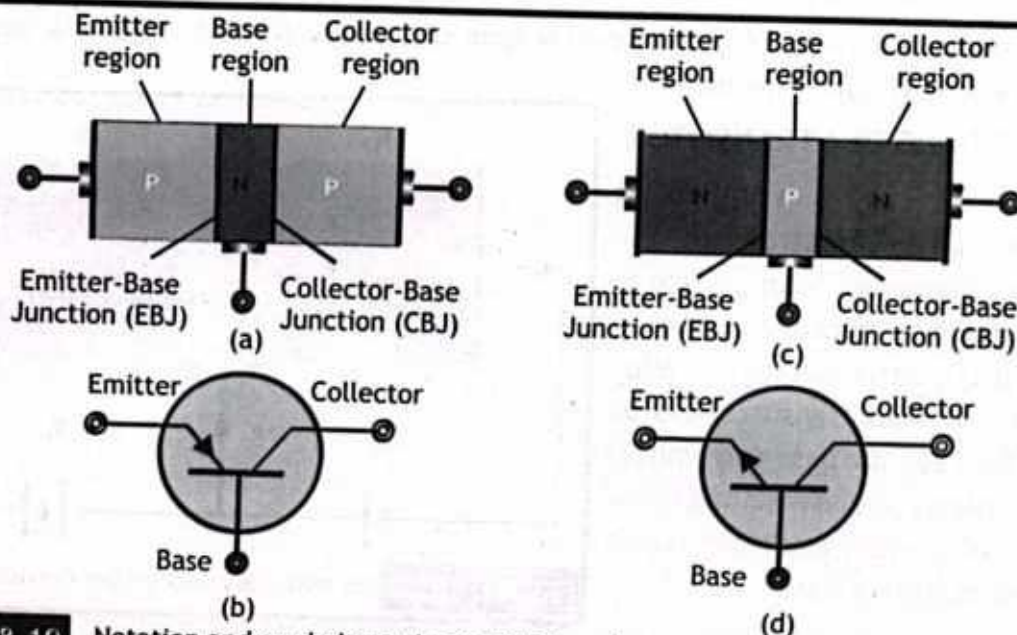


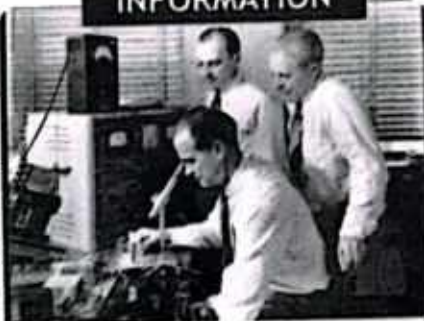
FIGURE 18.10 Notation and symbols used with PNP transistor and NPN transistor.

In general, all transistors have three regions: base (B), collector (C), and emitter (E).

- **Emitter:** It is moderately sized and heavily doped region.
- **Base:** It is at the center of the transistor. It is thin and lightly doped.
- **Collector:** It is larger than the emitter and is moderately doped.

A transistor is a three-terminal semiconductor device that consists of two p-n junctions namely BE and CE. A transistor is constructed in such a way that a lightly doped region called base is sandwiched between two regions called the emitter and collector. The function of a transistor is to amplify current. This makes them useful as switches or amplifiers. They have an extensive use in electronic devices like televisions, radio transmitters and mobile phones.

INFORMATION



In 1948, scientists Walter Brattain, John Bardeen, and William Shockley developed a device known as a transistor at Bell Laboratories. This invention was awarded the 1956 Nobel Prize in Physics. Transistor is the basis of the integrated circuits that run our computers and many modern technologies.

18.6.1 TYPES OF TRANSISTOR

Transistors are made in two types: PNP and NPN.

A. NPN Transistor: An NPN transistor is made by joining one P-type semiconductor in between two N-type semiconductors. Here a lightly doped P-type semiconductor is sandwiched between two heavily doped N-type regions.

B. PNP Transistor: A PNP transistor is made by sandwiching a N-type semiconductor in between two P-type semiconductors. Here a lightly doped N-type semiconductor is sandwiched between two heavily doped P-type regions.

18.6.2 WORKING OF A TRANSISTOR

When no voltage is applied at transistor's base, electrons in the emitter are prevented from passing to the collector side because of the pn junction. If a negative voltage is applied to the base of NPN transistor, the pn junction between the base and emitter becomes reverse biased resulting in the formation of a wider depletion region that prevents current flow.

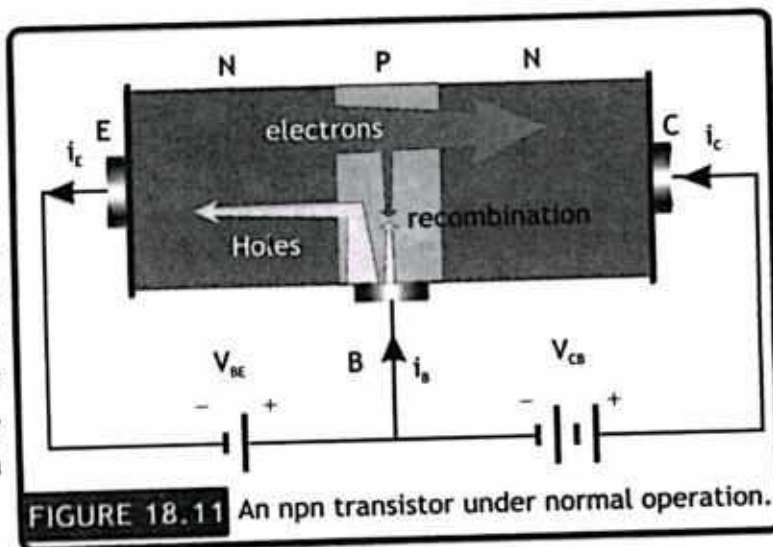


FIGURE 18.11 An npn transistor under normal operation.

Usually, two batteries are required for normal operation of a transistor; let us name these batteries as V_{BE} and V_{CB} (as shown in figure 18.11). For an NPN transistor, the negative terminal of the battery V_{BE} is connected to the N-type emitter and the positive terminal of the same battery is connected to the P-type base.

Therefore, the emitter-base junction of the transistor is forward biased. In the collector circuit, the N-type collector is connected to the positive terminal of the battery V_{CB} and the P-type base is connected to the negative terminal of the same battery. Hence the collector-base junction of the transistor is reverse biased.

Electrons enter the emitter from the negative terminal of battery V_{BE} and flow toward the junction. The forward bias has reduced the potential barrier of the emitter-base junction. The electrons then combine with the hole carriers in the base to complete the emitter base circuit. However, the base is a very thin region, about 0.001 inches. Most of the electrons flow on through to the collector as the collector terminal is connected to positive terminal of the battery V_{CB} and this reverse biased potential is very large so most of the majority charge carriers are attracted and will cross the large base to collector depletion region due to large reverse biased potential.

Direction of conventional current in the external circuit is shown in figure 18.11. It can be seen that sum of collector current (I_C) and base current (I_B) is equal to the emitter current (I_E), i.e.

$$I_E = I_B + I_C \quad \text{--- 18.1}$$

Approximately 95 % to 98 % of the current through the transistor is from an emitter to collector and about 2 % to 5 % of the current moves from emitter to base. The ratio between collector current and base current gives the current gain (β), i.e.

$$\text{Current gain } \beta = \frac{I_C}{I_B} \quad \text{--- 18.2}$$

Equation (18.2) gives the static or dc value of β . The dynamic or ac value is calculated for changes in the current values. The ratio between collector current and emitter current gives the current gain (α), i.e.

$$\text{Current gain } \alpha = \frac{I_C}{I_E} \quad \text{--- 18.3}$$

18.6.3 ROLE OF TRANSISTOR IN ADVANCEMENT OF COMPUTER TECHNOLOGY

The transistor is an important invention that changed the history for computers. Before transistors, digital circuits were composed of vacuum tubes. The vacuum tube used to amplify voice but the tubes consumed power, created heat and burned out rapidly, also requiring high maintenance. Transistors are commonly used in digital devices because they are both economical and act as rapid-response switches.

Transistors transformed the world of electronics and had a huge impact on computer design. Transistors made of semiconductors replaced tubes in the construction of computers. By replacing bulky and unreliable vacuum tubes with transistors, computers could now perform the same functions, using less power and space. With advances in engineering, the number of transistors that can be fit per unit area onto a circuit board has continued to increase dramatically; this has rapidly enhanced computing power. The first generation of computers used vacuum tubes; the second generation of computers used transistors; the third generation of computers used integrated circuits; and the fourth generation of computers used microprocessors.

Example 18.1

When collector current in a junction transistor is 99.9 mA and base current is 0.1 mA, how much is the emitter current?

GIVEN:

Collector current ' I_c ' = 99.9 mA

Base current ' I_b ' = 0.1 mA

SOLUTION:

The relationship between emitter, base and collector current is: $I_e = I_b + I_c$

putting values $I_e = 99.9 \text{ mA} + 0.1 \text{ mA}$

Therefore $I_e = 100 \text{ mA or } 0.1 \text{ A}$

ANSWER

Emitter current will be 0.1 A.

Example 18.2

Find the value of base current required to turn on the transistor for a collector current of 150 mA, for a transistor having current gain $\beta = 190$.

GIVEN:

Collector current ' I_c ' = 150 mA

Current gain ' β ' = 190

SOLUTION:

The relationship for current gain is: $\beta = \frac{I_c}{I_b}$ or $I_b = \frac{I_c}{\beta}$ putting values $I_b = \frac{150 \text{ mA}}{190}$

Therefore

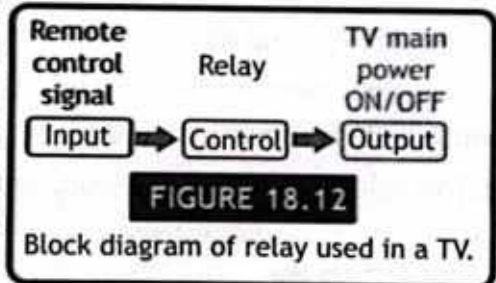
$I_b = 0.789 \text{ mA}$

ANSWER

Base current to run transistor will be around 0.8 mA.

18.7 RELAYS AND SWITCHING CIRCUITS

A Relay is an electrically operated switch that open and close the circuits by receiving electrical signals from outside sources. It consists of a set of input terminals for a signal and a set of operating contact terminals. For example consider figure 18.12, when you push the button on a TV remote to watch TV, it sends an electrical signal to the relay inside the TV, turning the main power ON.



Relays are very important in electronics. These are used to control a high power or high voltage circuit (or devices) with a low power circuit. A relays embedded in electrical products receive an electrical signal and send the signal to other equipment by turning the switch ON and OFF. For example:

- A timer circuit with a relay could switch power at a preset time.
- Relays are used to protect electrical circuits from overload or faults.
- Relays are used to turn on/off high-power devices like lamps or garage door motors with just a small DC voltage signal.

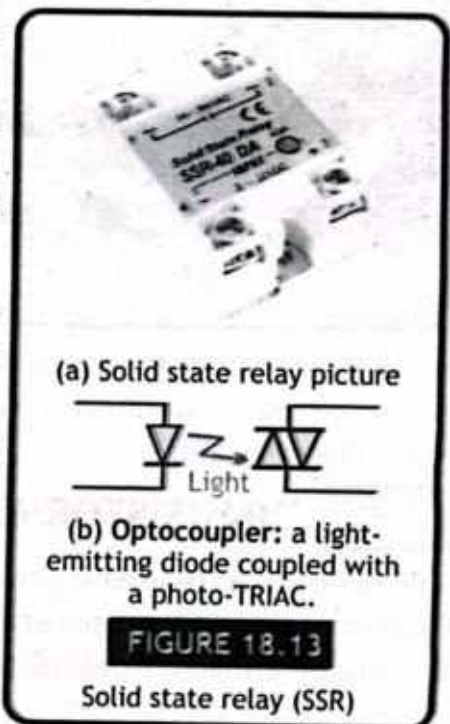
18.7.1 TYPES OF RELAY

There are various types of relays used in many applications to control different amounts of currents and number of circuits.

Relay technology can be divided into two main categories: Movable contacts (mechanical relay) and no movable contacts.

A. Movable Contacts (Mechanical Relay): This type of relay has contacts that are mechanically motivated to open/close by a magnetic force to switch signals, currents and voltages ON or OFF.

B. No Movable Contacts: Solid state relay (SSR), as shown in figure 18.13 (a), is an example of No-movable contact. It does not have any moving part, thus increasing long-term reliability. A solid state relay uses semiconductor and electrical switching device, activated by the control signal, to switch the controlled load. An optocoupler (a light-emitting diode coupled with a photo transistor or photo-TRIAC) can be used to isolate control and controlled circuits, as shown in figure 18.13 (b). Solid state relay (SSR) is commonly used for two reasons; a faster-switching process and durability.



18.7.2 OPERATING PRINCIPLES OF SOLID STATE RELAYS

Solid State relays operate according to the following principles.

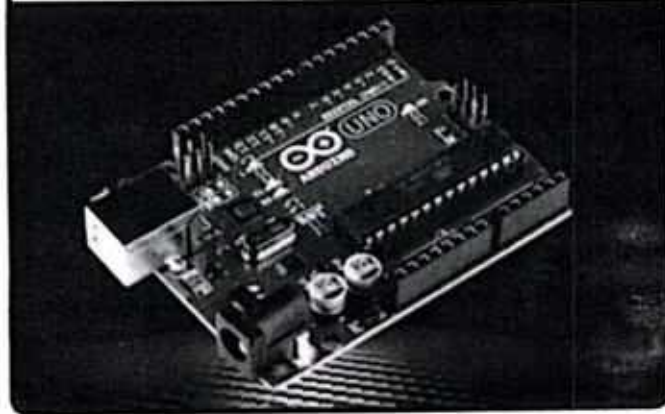
1. The LED lights up when the current is connected at the input side as shown in figure 18.14 (a).
2. The light sent by the LED will be converted into voltage gain when it is received by the photodiode as shown in figure 18.14 (b).
3. This voltage will be a gate voltage to derive the transistor via control circuit as shown in figure 18.14 (c).

SCIENCE TIDBITS



You can use a microcontroller (such as Arduino) to create the logic for when to turn your lamp ON and OFF. It uses an electrical relay to do the switching of the lamp.

This makes it easy to make lights that activate only at night, control your garage door motor or other home appliances with a signal generated by your phone.



By the operation of these electronic circuits, signals (currents and voltages) are switched ON or OFF electronically.

18.8 TRANSISTOR AS A SWITCH

The transistor can be used as a switch if biased in the saturation and cut-off regions. The collector C and emitter E of transistor behave as the terminal of switch. The base 'B' and emitter 'E' act as the control terminal to decide the state of the switch either on or off. The main reason behind

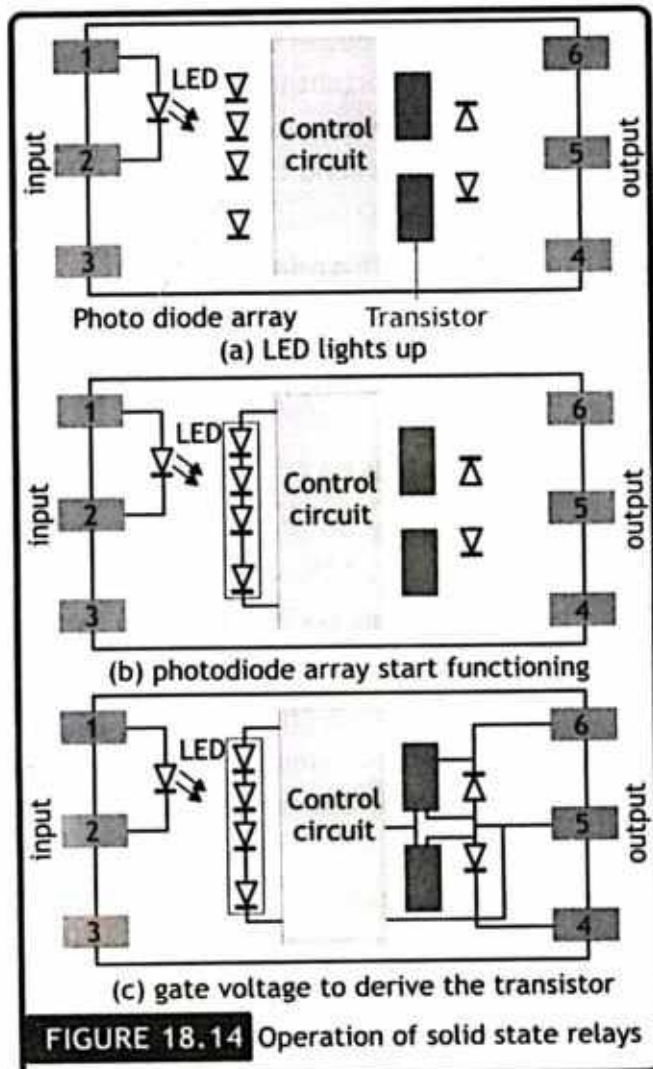


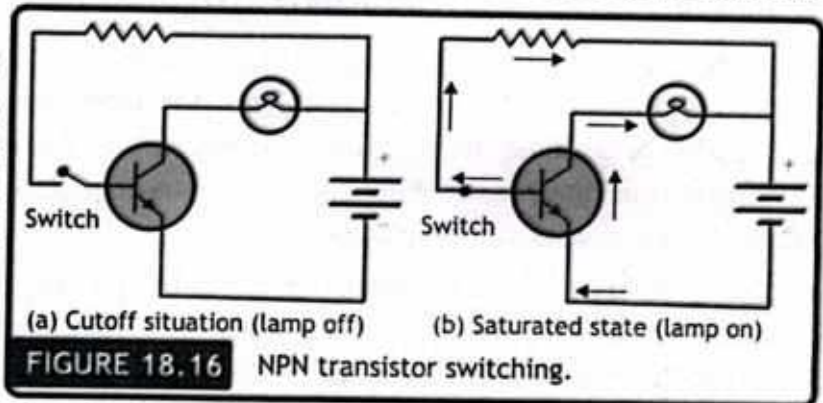
FIGURE 18.14 Operation of solid state relays

using the transistor as a switch is that the current at the base (I_b) controls the current present at the collector (I_c): as from the relation $I_c = \beta I_b$. If the current at the base exceeds the minimum cut-off value, then the behavior of the transistor is like a closed switch otherwise it will behave like an open switch.

Suppose we have a lamp that we want to turn on and off with a switch, as shown in the figure 18.15 (a). Let's introduce a transistor in place of the switch as shown in figure 18.15 (b).

If the base of transistor is not connected to a suitable voltage, the base current will become zero. Consequently, the transistor cannot turn on. So, we must connect a switch between the base and collector wires of the transistor.

If the switch is open as shown in figure 18.16 (a), there will be no current through the base. According to the relation $I_c = \beta I_b$, no current will flow from the collector to the emitter. In this situation, the resistance between C and E become infinite and CE behaves as an open



switch. In this state, the transistor is said to be in cutoff.

If the switch is closed as shown in figure 18.16 (b), current will be able to flow from the base to the emitter of the transistor through the switch. This base current will enable a much larger current flow from the collector to the emitter due to small resistance between C and E, thus lighting up the lamp. In this state circuit current is maximum and the transistor is said to be saturated.

18.9 DIGITAL ELECTRONICS

Digital electronic circuits deal with the situation having only two 'states': ON or OFF, TRUE or FALSE, HIGH or LOW, and YES or NO etc. For example, consider a circuit as shown in figure 18.17.

There are only two possible positions to flip a light switch i.e., ON or OFF (It's of no concern to you that there could be 110 volts, 120 volts or 220 volts i.e., fluctuating analog "signal", running

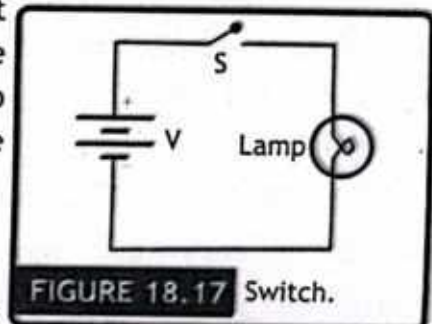
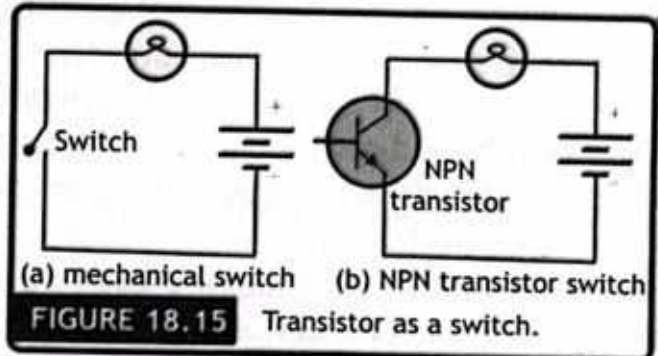


TABLE 18.1 SWITCHING

Switch (Input)	Lamp (Output)
Open	OFF
Closed	ON

through the electrical wiring connected to the light switch).

We call state of switch as input and state of current or lamp as output. When the switch is open no current passes through the circuit and lamp is OFF. In other words, when input is 0 output is also 0. When the switch is closed current passes through the circuit and lamp is ON. In other words, when input is 1 output is also 1. The possible combinations of input and output states of this circuit are shown in Table 18.1.

Like this ON/OFF switching, the same logic used to build the digital electronic circuits inside your laptop computer, GPS device and smart-phone. The two states can be best operated mathematically if the states are numerically represented by binary digits 1 and 0, also known as Boolean variables. English alphabets (A, B, C, etc.) are used to represent the Boolean variables. Boolean algebra is a formal way of describing logical operations. It is based on three basic logical operators such as: AND, OR and NOT.

18.9.1 CONVERTING ANALOGUE DATA TO DIGITAL DATA

The Analogue-to-Digital Converter (ADC) enables microprocessor-controlled circuits, like Arduinos and Raspberry Pi, to connect with the real world. In reality, analogue signals vary continuously and come from different sources and sensors that can detect sound, light, temperature, or movement. Many digital systems engage with their surroundings by measuring these analogue signals from transducers.

So it is necessary to have an electronic circuit which can convert the continuously changing analogue signals to discrete digital signals, such circuits are known as Analogue-to-Digital Converters. Whereas Digital-to-Analogue Converter (DAC) allow to convert discrete digital signal to analogue signals.

18.9.2 UNIT OF DATA IN COMPUTING

Analogue signals can be continuous and provide an infinite number of different voltage values. On the other hand, digital circuits work with binary signal which have only two discrete states, a logic "1" (HIGH) or a logic "0" (LOW). Each digit in binary (0 or 1) is called a bit, which is an abbreviation of binary digit.

18.9.3 LOGIC GATES: THE BUILDING BLOCKS OF ALL DIGITAL ELECTRONIC CIRCUITS

Electronic devices are built from digital logic circuits. Logic gates are the main building blocks of all digital logic circuits. These circuits can act as switches and convert incoming voltage into binary electrical pulses of high (or 1) and low (or 0). Digital electronic circuits use to implement binary/logical operations are known as logic gates.

Logic gates can have one or more inputs but only one output. Electronic devices are usually made from large assemblies of logic gates, often packed in integrated circuits. Common logic gates are AND, OR, NAND, NOR and NOT. Set of inputs and outputs of a logic system in binary form is called truth table.

18.10 FUNDAMENTAL LOGIC GATES

The three logic gates AND, OR and NOT are known as fundamental logic gates.

18.10.1 AND GATE

Consider the figure 18.18 (a) in which a lamp is connected in series with a battery using two switches (A and B) as two inputs.

There are following four possible states of these two switches:

- When both the switches A and B are open then the lamp is OFF.
- When the switch A is open but B is closed then the lamp is OFF.
- When the switch A is closed but B open then the lamp is OFF.
- When both the switch A and B are closed then the lamp is ON.

It is clear that "the lamp will glow only if both the switches are closed". A logic gate which implements such action is known as AND gate. Symbol of AND gate is shown in figure 18.18 (b).

Boolean expression for AND operation is:

$$X = A \cdot B$$

(read as "X equals A AND B").

Where the symbol dot ($\cdot$) represents the AND operation. The truth table of AND operation is shown in Table 18.2 AND gate has two or more inputs and only one output. Output of AND gate will be '1' only when all of its inputs are '1', and for all other situations output of AND gate will be '0'.

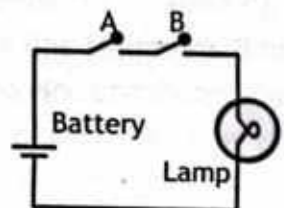
18.10.2 OR GATE

Consider the figure 18.19 (a) in which a lamp is connected in parallel with a battery using two switches (A and B) as two inputs.

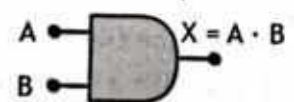
There are following four possible states of these two switches:

- When both the switches A and B are open then the lamp is OFF.
- When the switch A is open and B is closed then the lamp is ON.
- When the switch A is closed and B is open then the lamp is ON.
- When both the switches A and B are closed then the lamp is ON.

It is clear that "the lamp will glow if at least one of the switches is closed". A logic gate which implements such action is known as OR gate. Symbol of OR gate is shown in figure 18.19 (b).



(a) Switch depiction



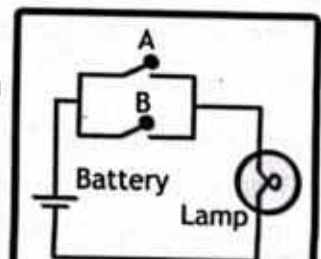
(b) Circuit symbol

FIGURE 18.18

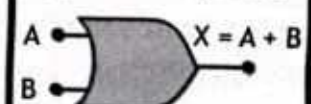
AND gate

TABLE 18.2 AND GATE

Switch (Input)		Lamp (Output)
A	B	$X = A \cdot B$
0	0	0
1	0	0
0	1	0
1	1	1



(a) Switch depiction



(b) Circuit Symbol

FIGURE 18.19

OR gate

Boolean expression for OR operation is: $X = A + B$

(read as "X equals A OR B").

Where the symbol plus (+) represents the OR operation. The truth table of OR operation is shown in Table 18.3, where A and B are inputs and X is output (lamp). OR gate has two or more inputs and only one output. Output of OR gate will be '0' only when all of its inputs are '0', and for all other situations output of OR gate will be '1'.

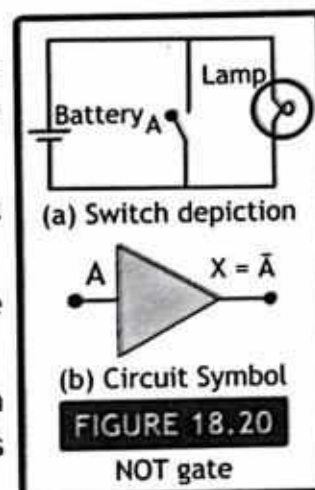
TABLE 18.3 OR GATE		
Switch (Input)		Lamp (Output)
A	B	$X = A + B$
0	0	0
1	0	1
0	1	1
1	1	1

18.10.3 NOT GATE

Consider the figure 18.20 (a) in which a lamp is connected in parallel to a battery with a switch A as inputs. There are two possible states of these two switches which are given below:

- When the switch A is open, current will pass through the lamp and it will glow.
- When the switch A is closed, no current will pass through the lamp due to large resistance of its filament and it will not glow.

It is clear that "the lamp will glow if the switch is open". A logic gate which implements such action is known as NOT gate. Symbol of NOT gate is shown in figure 18.20 (b).



Boolean expression for NOT operation is:

$$X = \bar{A}$$

(read as "X equals A NOT")

Where a line or bar over the symbol represents the NOT operation.

TABLE 18.4 NOT GATE	
Switch (Input)	Lamp (Output)
A	$X = \bar{A}$
0	1
1	0

The truth table of NOT operation is shown in Table 18.4, where A is input and X is output (lamp). NOT gate has one inputs and one output. NOT operation inverts the state of Boolean variable. Output of NOT gate will be '0' when its inputs are '1', and vice versa.

18.11 UNIVERSAL LOGIC GATES

The logic gates NAND and NOR gates are known as "universal gates" because they can be used to make all the other gates.

18.11.1 NAND GATE

NAND gate is obtained by coupling a NOT gate with the output terminal of the AND gate, as shown in figure 18.21 (a). The NOT gate inverts the output of the AND gate. Thus, NAND gate is the

reciprocal of AND gate. Symbol of NAND gate is shown in figure 18.21 (b) (small circle shows the NOT operation).

Boolean expression for NAND operation is:

$$X = \overline{A \cdot B}$$

(read as "X equals A AND B NOT").

The truth table of NAND operation is shown in Table 18.5.

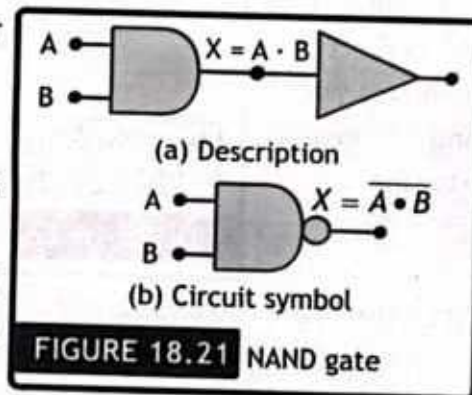


TABLE 18.5 NAND GATE		
Switch (Input)		Lamp (Output)
A	B	$X = \overline{A \cdot B}$
0	0	1
1	0	1
0	1	1
1	1	0

18.11.2 NOR GATE

The NOR gate is obtained by coupling the output of the OR gate with the NOT gate, as shown in figure 18.22 (a). The NOT gate inverts the output of the OR gate. Symbol of NOR gate is shown in figure 18.22 (b).

Boolean expression for NOR operation is:

$$X = \overline{A + B}$$

(read as "X equals A OR B NOT").

The truth table of NOR operation is shown in Table 18.6.

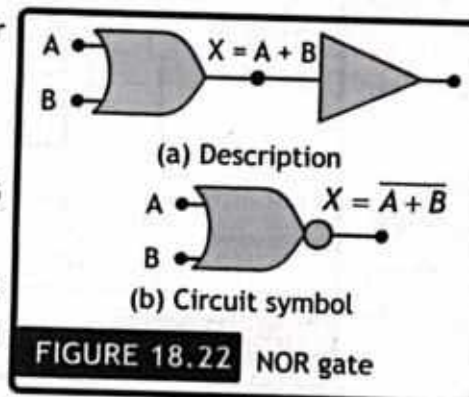


TABLE 18.6 NOR GATE		
Switch (Input)		Lamp (Output)
A	B	$X = \overline{A + B}$
0	0	1
1	0	0
0	1	0
1	1	0

18.12 USES OF LOGIC GATES

Every day in our lives, we encounter many things that work with the help of logic gates. Logic gates are used in electronic circuits to do useful tasks. These are also used for security purposes e.g; burglar alarm and fire extinguisher etc.

18.12.1 BURGLAR ALARM

A burglar alarm system detect movement or the opening of doors and windows using sensors and contacts, and aloud alarm is emitted to warn others.

A simple burglar alarm circuit can be made by using an AND gate. We have two inputs which are the person sensor and the alarm switch, as shown in figure 18.23.

- If both the person sensor and the alarm switch are ON, then the burglar alarm is activated.
- If only one input is ON, the burglar alarm will not be activated.

For example, if the person sensor is ON but the alarm switch is not, the burglar alarm will not be activated. When the person sensor detects the person, it gives the signal 1. Then the alarm switch will also give a signal 1. Thus, "1" and "1" give an output "1" which will make the alarm to ring.

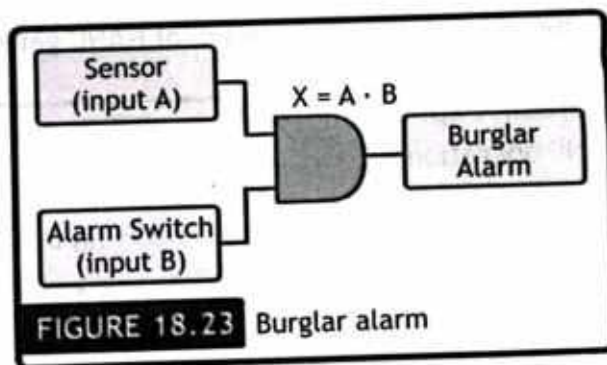


FIGURE 18.23 Burglar alarm

18.12.2 FIRE EXTINGUISHER

Fire alarm circuit is a simple circuit that detects the fire and activates the Siren Sound. Fire Alarm Circuits are very important devices to detect fire in the right time and prevent any damage to people or property. The circuit is required to switch on when activated then sound a buzzer continuously. A fire alarm circuit using a NAND gate is shown in figure 18.24.

The buzzer is initially off so the output from A is 0. This requires the output from gate B must be 1. There being no fire, the thermistor is cold and its resistance is high, so there is a voltage across it and so the two inputs to gate A are both 1.

When the thermistor is warmed by a fire, its resistance falls, as does the voltage across it, and input 1 falls to 0. The output from A becomes 1 so there is a voltage across the buzzer, which sounds.

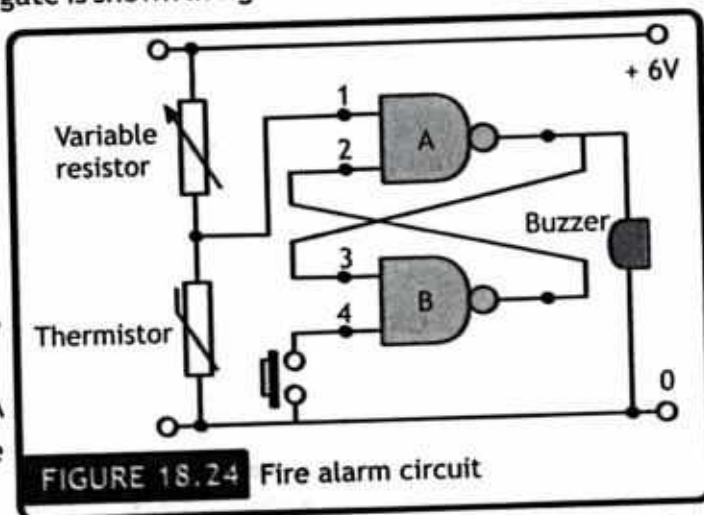


FIGURE 18.24 Fire alarm circuit

Input 3 to B becomes 1, and since input 4 is also 1, the output from B becomes 0. The inputs to A are 1 and 0, so the output stays at 1. To reset the alarm, the reset switch R must be pressed. This will make input 4 into a 0, so the output from B will be 1 and A will have inputs of 1 and 1, so output 0 as originally.

18.13 ANALOGUE AND DIGITAL ELECTRONICS, A COMPARISON

Based on types of signals used, the electronics can be broadly classified into two branches: Analog Electronics and Digital Electronics. Analog electronics is the branch of electronics that deals with the electronic systems and devices with the continuous time signals. Analog electronics can be used to amplify signals, filter noise, and perform a wide variety of other functions. In analog electronics, two types of components are used to design the systems which are: the active elements such as diode, transistors, etc. and the passive elements such as resistors, capacitors, inductors, etc. Analog electronics is widely used in radio and audio devices such as FM radios, TVs, telephones, etc.

Digital electronics is the branch of electronics that deals with the electronic systems and devices with digital signals or discrete time signals. The digital electronics uses binary logic function to perform operations, the basic mean of binary logic function is that it has only two states 'active high' and 'active low'. One of the most common application of digital electronics is in computers. Other applications include, data processing and storage, automation and digital watches. Digital electronics systems are usually made from a combination of logic gates, often packaged in an integrated circuit (IC). Digital electronics uses active components only. Digital system has many advantages over analogue, some are given below:

- Digital system has small size.
- Digital systems are generally easier to design.
- Accuracy and precision are greater.
- Digital systems need less power to operate.
- Operation can be programmed.
- Digital circuits are not affected by noise (noise is fluctuations in voltage).

An analog quantity (or signal) is one having continuous values over limit. For Example, temperature, time, pressure, sound and distance etc., are analogue quantities. The digital quantity (or signal) is one having a set of discrete values over limit.

INFORMATION

Fire Alarm Circuits and Smoke Sensors are a part of the security systems which help in detecting or preventing damage. Installing Fire Alarm Systems and Smoke Sensors in commercial buildings like offices, hospitals, schools, shopping malls and other public places is compulsory.

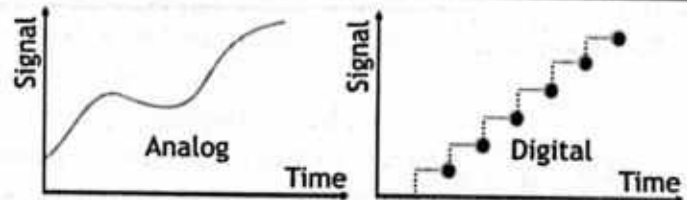
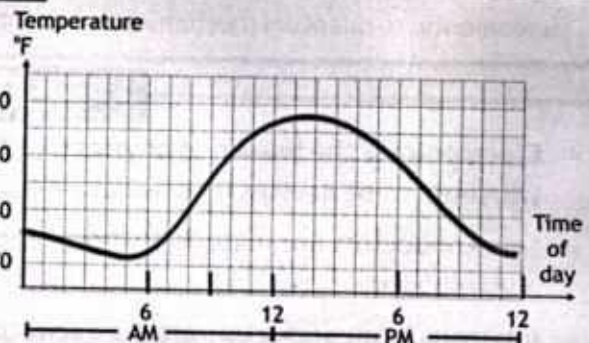


FIGURE 18.25 Operation of solid state relays

INFORMATION

The temperature of air varies in a continuous fashion during 24 hours of a day. If we plot a graph between temperature and time, we get graph as shown below. This graph shows that temperature varies continuously with time. The air temperature does not go from, say, 75 °F to 80 °F instantaneously, it takes the infinite values in between. Therefore, we say that temperature is an analogue quantity.



These quantities change in discrete steps. Graphs of both analogue and digital signals are shown here in figure 18.25.

SCIENCE
TIDBITS

In today's technological world, both analog and digital electronics are equally used to implement most efficient and fast processing systems such as robotics, quantum computing, telecommunication, etc.



18.14 QUANTUM COMPUTERS

Quantum computing uses phenomena in quantum physics to create new ways of computing. Unlike traditional computers that use bits to represent information as either a 0 or a 1, quantum computers use qubits (or quantum bit), which can exist in multiple states simultaneously. This allows quantum computers to perform complex calculations at an exponentially faster rate than classical computers. Quantum computers are still in early stages of development, and have to overcome manufacturing challenges such as core components only functioning at very cold temperatures that are at almost absolute zero. Most qubits must be cooled to within a few thousandths of a degree of absolute zero to eliminate thermal noise and vibrations, which tend to destroy the information contained in the qubits.

CAN YOU
TELL?

A qubit (or quantum bit) is the quantum mechanical analogue of a classical bit. In classical computing the information is encoded in bits, where each bit can have the value zero or one. In quantum computing the information is encoded in qubits. In a classical system, a bit would have to be in one state or the other.

However, quantum mechanics allows the qubit to be in a coherent superposition of multiple states simultaneously. This property is fundamental to quantum mechanics and quantum computing.

Bit
(Classical Computing)

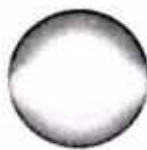
0



1

Qubit
(Quantum Computing)

0



1

SUMMARY

- Electronics is the branch of physics that helps to study the emission and behaviour of electrons with electronic devices is known as electronics.
- Semiconductors are materials whose electrical conductivity falls between those of conductors and insulators.
- **Intrinsic Semiconductors** are pure semiconductors (such as Si or Ge).
- **Extrinsic Semiconductors** are those semiconductors that are doped with some specific impurities.

- Pentavalent impurities such as phosphorus, arsenic, antimony, and bismuth have five valance electrons and belong to group V-A of periodic table.
- Trivalent impurities e.g., boron, aluminum, indium, and gallium have three valance electrons and belongs to group III-A of periodic table.
- Majority Charge Carriers in n-type semiconductor are electrons and in p-type semiconductor are holes.
- Forward Bias is the condition when the positive terminal of a DC source is connected to p-type and negative terminal is connected to n-type semiconductor of a pn junction.
- Light-Emitting Diode emits energy in the form light when the electric current passes through it.
- Transistor acts as both a transmitter and resistor. It is made in two types: PNP and NPN.
- Relay is an electrically operated switch that open and close the circuits by receiving electrical signals from outside sources.
- Analogue-to-Digital Converter is electronic circuit which can convert the continuously changing analogue signals to discrete digital signals.

Digital-to-Analogue Converter (DAC) allow to convert discrete digital signal to analogue signals.

- Bit is each digit in binary (0 or 1), which is an abbreviation of binary digit.
- Logic gates implement binary operations to digital electronic circuits.
- Fundamental logic gates are three logic gates AND, OR and NOT logic gates.
- Universal logic gates are the logic gates NAND and NOR because they can be used to make all the other gates.
- Quantum Computing uses phenomena in quantum physics to create new ways of computing.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Q1. Choose the best possible option in the following questions.

- The approximate potential barrier for germanium and silicon transistors are _____ respectively.
 A. 0.3 V and 0.7 V B. 0.7 V and 0.3 V C. 0.7 V and 0.5 V D. 0.5 V and 0.7 V
- The current ratio of a beta is:
 A. I_c / I_e B. I_b / I_c C. I_e / I_b D. I_c / I_b
- Which of the following relation is correct for a transistor?
 A. $I_c = I_b + I_e$ B. $I_b = I_c + I_e$ C. $I_e = I_c + I_b$ D. $I_e = I_c - I_b$

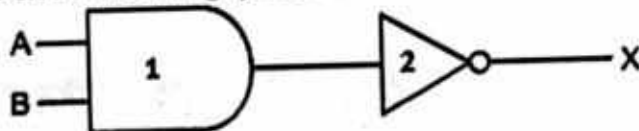
4. The heavily doped region of the transistor is:
 A. Emitter B. Collector C. Base D. All of these
5. A transistor has _____ PN junctions.
 A. 1 B. 2 C. 3 D. 4
6. If $I_E = 1 \text{ mA}$ and $I_C = 0.25 \text{ mA}$ then the I_B value will be:
 A. 0.75 mA B. 0.95 mA C. 0.65 mA D. 0.85 mA
7. If the gain β of a NPN transistor is 200 and its collector current is 4 mA. The value of base current will be:
 A. 20 μA B. 25 μA C. 30 μA D. 35 μA
8. The majority charge carriers in the emitter of an NPN transistor are:
 A. pentavalent atoms B. electrons C. trivalent atoms D. holes
9. The output of a NAND gate is 0 when:
 A. A is '1' and B is '0' B. A is '0' and B is '1' C. both A and B are '0' D. both A and B are '1'
10. If $X = A + B$, then X is 0 when::
 A. both A and B are '0' B. A or B is '0' C. A is '0' and B is '1' D. A is '1' and B is '0'
11. The output of a NOR gate is '1' when:
 A. both of its inputs are '0' B. both of its inputs are '1' C. any of its inputs is '0' D. any of its inputs is '1'
12. The logical operation performed by this gate is:
 A. AND B. NOR
 C. NAND D. OR



CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Consider the given logic circuit:



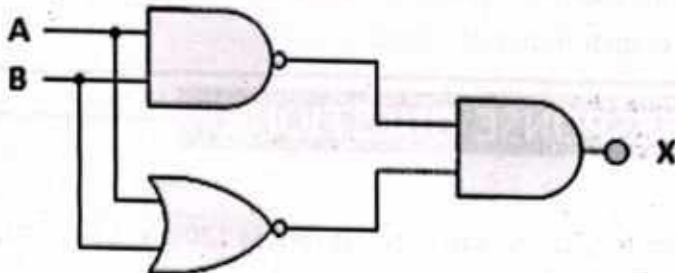
a) Identify the logic gates in the circuit:

Name of the gate 1 is _____

Name of the gate 2 is _____

b) Draw a single logic gate that can replace the given logic circuit

2. Write the expression for the following combination of logic gates. Here A and B are inputs and X is output. Also complete its truth table.



TRUTH TABLE		
Inputs		Output
A	B	X =
0	0	
1	0	
0	1	
1	1	

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. How do N-type materials and forward biasing affect semiconductor devices?
2. Why are pentavalent impurities called donors and trivalent impurities acceptors?
3. How do relays improve electrical systems? Give examples.
4. How do the three terminals of a transistor work together to amplify signals?
5. Why is one transistor region highly doped and another the smallest in size?
6. What does the arrow in a transistor symbol represent, and why is it important?
7. Explain the normal biasing of an NPN transistor. What happens if it is reversed?
8. How does biasing (forward or reverse) change the depletion region in a diode?
9. Why does an n-type or p-type material have zero net charge?
10. Why are NAND and NOR gates called universal gates?
11. For a NOR gate, how do you determine the output for different inputs?
12. What makes digital systems better than analog systems?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. What is an extrinsic semiconductor? How do impurities affect its conductivity?
2. Describe how a PN junction forms and explain the effects of forward and reverse biasing on it.
3. Using a diagram, explain how a solid-state relay works and its advantages over mechanical relays.
4. Describe how an NPN transistor operates, focusing on the movement of charge carriers.

5. How can a transistor function as a switch? Provide examples of its use in circuits.
6. Explain the working of an OR gate with a circuit diagram. How does it process input signals?
7. How are logic gates used in burglar alarms and fire extinguishers? Explain with examples.
8. Discuss the challenges in development of quantum computers.

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. In a junction transistor, emitter current is 5.82 mA and base current is 120 μ A. Calculate the collector current.
(Ans. 5.7 mA)
2. For a 600 μ A base current and 30 mA collector current, how much is the current gain β ?
(Ans. 50)
3. Calculate the value of β gain if an emitter current is changed by 4 mA and the collector current is changes by 3.5 mA.
(Ans. 7)