CHAPTER 19

ELECTRONICS

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- describe the working of a diode.
- describe the action of a light-emitting diode in passing current in one direction only and emitting light.
- compare analog and digital electronics.
- explain that electronic devices are built from digital logic circuits (that can act as switches that can convert incoming voltage into binary electrical pulses of high and low (1 or 0).
- explain that Boolean logic is the basis for converting analog data to digital data (this includes knowing that 'bit' is the smallest unit of data in computing; either 1 or 0. Eight bits make up a byte).
- state in words and in truth table form, the action of logic gates (specifically of AND, OR, NAND, NOR, and NOT).
- identify the use of logic gates for security purposes (e.g: burglar alarm, fire extinguisher etc.).
- use circuit symbols for the logic gates.
- identify in given problems how Boolean switches can be put into combinations that then allow them to achieve logical operations.

Electronics is a branch of science that deals with the study and control of the flow of electrons in devices and circuits. It blends technical precision with innovative thinking, giving rise to advancements in areas such as artificial intelligence, renewable energy, and space exploration. From simple components like resistors to sophisticated microprocessors, each element contributes to the ever-evolving landscape of technology, providing many possibilities for innovation and shaping the future.

19.1 Semiconductors

Semiconductors are materials whose electrical conductivity lies between that of conductors and insulators. They are widely used in electronic devices because their conductivity can be controlled. The most common semiconductors are silicon (Si) and germanium (Ge). Their conductivity can be increased by adding a small amount of impurity, a process known as doping. There are two main types of doped semiconductors (N-type and P-type). In an N-type semiconductor, a small amount of a pentavalent impurity such as phosphorus or arsenic is added to silicon (Fig.19.1-a). These elements have five valence electrons; four form covalent bonds with silicon, while the fifth remains free to move. These free electrons are the majority charge carriers, which increase the conductivity of the semiconductor.

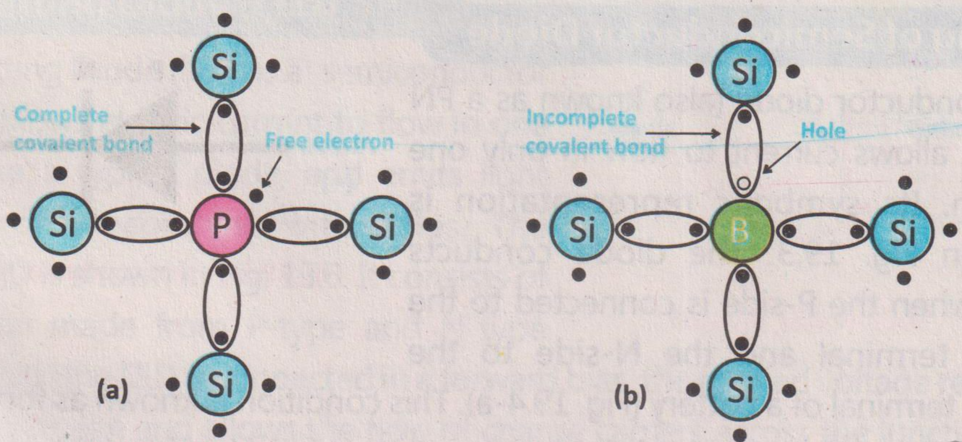


Fig. 19.1: (a) N-type semiconductors (b) P-type semiconductors

In a P-type semiconductor, a trivalent impurity such as boron or gallium is added to silicon (Fig. 19.1-b). These atoms have only three valence electrons, so one bond remains incomplete, creating a hole (a missing electron). Holes act as positive charge carriers, moving through the crystal and helping in current conduction.

PN Junction

When an N-type and a P-type semiconductors are joined together, they form a PN junction semiconductor diode. At the junction, electrons from the N-side and holes from the P-side recombine, creating a region without free charge carriers called the depletion region. This region acts as a barrier that prevents further movement of charges. To allow current to flow, an external voltage is applied to overcome this barrier. For silicon based diodes, the required voltage is about 0.7 V, and for germanium based diodes, it is about 0.3 V.

> **Tidbit**
>
> A diode is like a one-way road for current allowing it to flow in only one direction and blocks in the opposite direction.

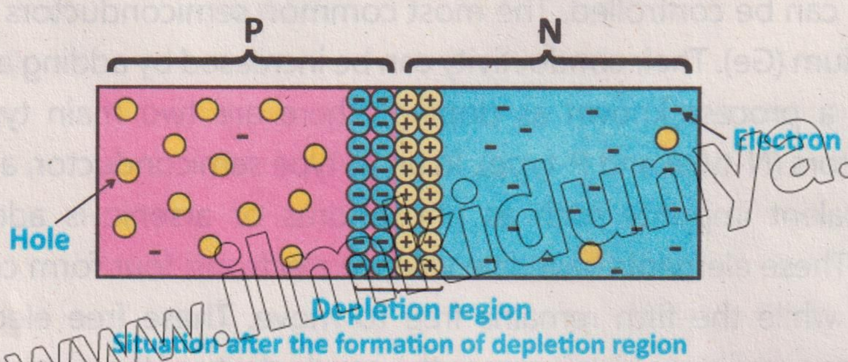


Fig.19.2: Schematic diagram of formation of PN junction

Working of Semiconductor Diode

A semiconductor diode (also known as a PN junction) allows current to flow in only one direction. Its symbolic representation is shown in Fig. 19.3. The diode conducts current when the P-side is connected to the positive terminal and the N-side to the negative terminal of a battery (Fig. 19.4-a). This condition is known as forward bias. In forward bias, the applied voltage reduces the potential barrier at the junction and narrows the depletion region. This enables charge carriers (electrons and holes) to easily cross the junction, causing the flow of current through the diode. In contrast, when the P-side is connected to the negative terminal and the N-side to the positive terminal of a battery, the diode is said to be in reverse bias (Fig. 19.4-b). In this condition, the depletion region widens, increasing the potential barrier and

Fig. 19.3: A semiconductor diode

preventing the flow of majority charge carriers. However, a very small current, known as leakage current, still flows due to the movement of minority carriers from both sides of the junction.

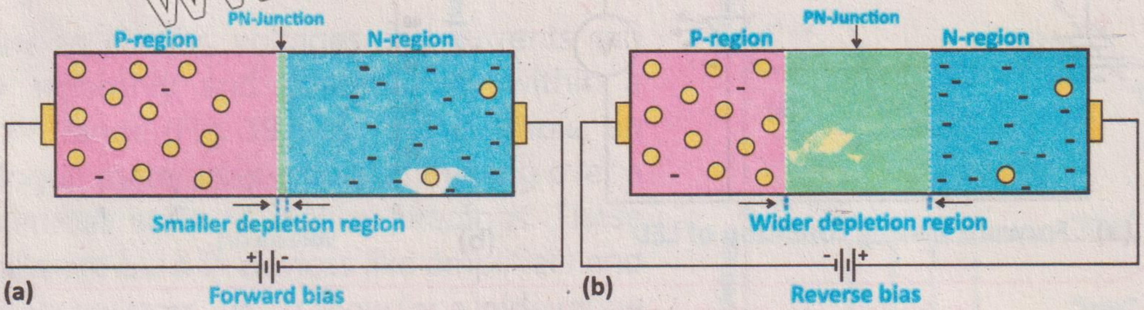


Fig. 19.4: Forward and reverse biasing of a PN junction showing changes in depletion region

The typical current-voltage (*I–V*) characteristic curve of a diode is shown in Fig. 19.5. In this graph, the diode conducts a significant current only in forward bias, whereas in reverse bias, it blocks the current almost completely. This property of diodes is important for their use in circuits such as rectifiers, voltage regulators, and electronic switches.

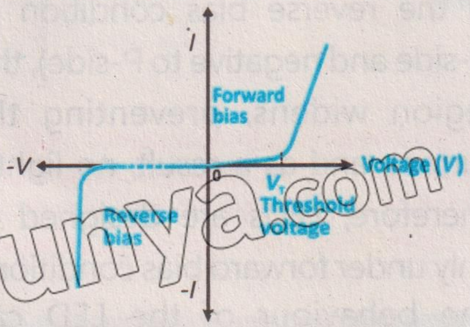


Fig. 19.5: *I-V* graph of a semiconductor diode

Light -Emitting Diode (LED)

A Light-Emitting Diode (LED) is a semiconductor device that allows electric current to flow in one direction, like a typical diode, and emits light when electrons recombine with holes. The symbol of LED is shown in Fig. 19.6. It consists of a PN-junction made from P-type and N-type materials. When the LED is connected in a forward bias, the applied voltage reduces the depletion region and allows the flow of charge carriers across the junction. As electrons from the N-type material move across and recombine with holes in the P-type material, energy is released in the form of photons, creating visible light.

Fig.19.6: LED symbol

The working of an LED under forward bias condition is shown in Fig. 19.7(a). Here, a simple circuit diagram demonstrates the LED setup with a resistor *R* to limit the current, a voltmeter V for the measurement of voltage across the LED, and an ammeter (mA) in series to measure the current flowing through the circuit.

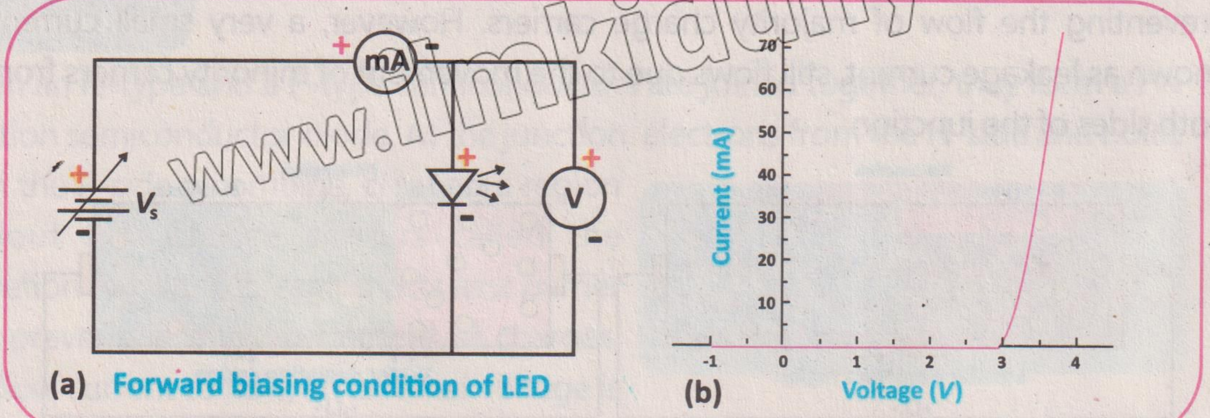


Fig. 19.7: (a) LED circuit in forward bias (b) *I–V* characteristic curve

In the reverse bias condition (positive to N-side and negative to P-side), the depletion region widens, preventing the flow of current, and as a result, no light is emitted. Therefore, LEDs are designed to function only under forward bias condition.

The behaviour of the LED can also be understood using a current-voltage (*I–V*) characteristic graph as shown in Fig. 19.7-b. In this graph, it is observed that initially small current flows as voltage increases. However, after a certain threshold voltage, a sudden sharp increase in current occurs, resulting in light emission.

The colour of the light produced by an LED depends on the materials used during its manufacture, affecting the wavelength (and thus the colour) of the emitted light. LEDs are highly efficient, durable, energy-saving, and are extensively used in a variety of applications including radios, lamps, digital clocks, calculators, video displays, remote controls, and modern lighting systems.

Thus, LEDs play an important role in both everyday life and advanced technologies by efficiently converting electrical energy directly into light.

Do You Know?

Diodes are Important

- The silicon diode is the simplest of all the semiconductor devices. It is also one of the most important. Without diodes, one can not build electronic equipment.
- Applications for diodes range from power supplies to cell phones and everything in between.

Tidbit

Unlike normal bulbs, LEDs do not waste much energy as heat. They instantly glow by simply letting current flow across a special junction.

Brain Teaser

In an LED, electrons meet holes and produce something surprising. What is released during this encounter heat, light, or sound?

19.2 Analog and Digital Electronics

Electronic circuits, devices, or systems are mainly divided into analog and digital types.

In analog circuits, voltages and currents can vary smoothly and continuously within a certain range (Fig. 19.8-a). For example, an analogue meter uses a pointer moving over a continuous scale to display readings. These circuits are used in devices like amplifiers and variable resistors, which allow for a wide range of adjustments, such as dimming a lamp to various brightness levels. In digital circuits, voltages have only two values: "high" (e.g., 5 V) or "low" (e.g., near 0 V) (Fig. 19.8-b). These circuits are used in switching systems, like a simple ON/OFF switch for a lamp. While digital electronics were once limited to computers, these are now widely used in modern telephones, radar systems, industrial machines, medical equipments, and household appliances. However, the quantities we perceive in daily life, such as sound or light, are analog and cannot be directly processed by digital circuits. To bridge this gap, an analog-to-digital converter (ADC) is used. It converts analog signals into digital binary form for processing by computers (Fig. 19.9). The ADC works by sampling the analog signal at regular intervals and converting each sample into a binary number that represents its voltage level.

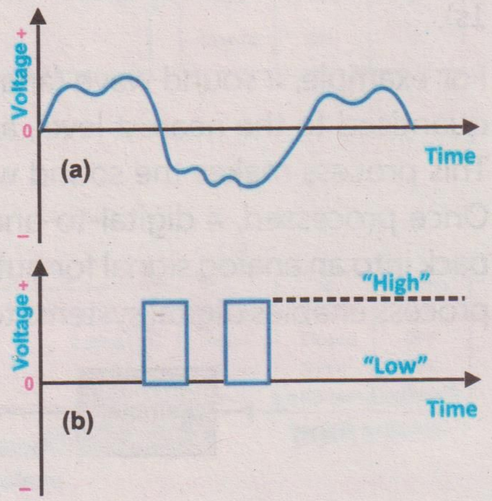


Fig. 19.8: Comparison of analog and digital signals: (a) analog signal varies continuously over time, while (b) digital signal switches between discrete "high" and "low" levels

Tidbit

Analog signals are continuous like ocean waves. Digital signals are sharp like stair steps just highs and lows (1's and 0's).

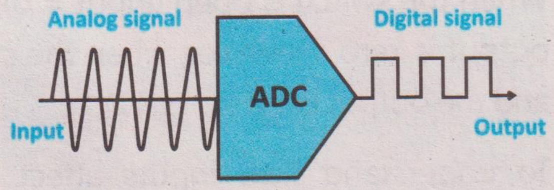


Fig. 19.9: Analog-to-digital converter (ADC)

Conversion from Analog to Digital Data

Analog data, such as sound or light, is continuous and can take any value within a range. In contrast, digital systems use binary data (0s and 1s), which is discrete. To convert analog data into a digital format, an analog-to-digital converter (ADC) is used. The process works as follows (Fig. 19.10).

1. **Sampling:** The continuous analog signal is measured at regular intervals.

2. **Quantization:** Each sampled value is rounded to the nearest predefined level.

3. **Encoding:** The quantized values are then converted into binary numbers (0s and 1s).

For example, a sound wave (analog) is measured at regular intervals, each value is quantized to the nearest level, and then encoded into a series of binary numbers. This process makes the sound wave usable by digital devices, such as computers. Once processed, a digital-to-analog converter (DAC) can convert the binary data back into an analog signal for output, such as playing sound through a speaker. This process enables digital systems to handle real-world, continuous data efficiently.

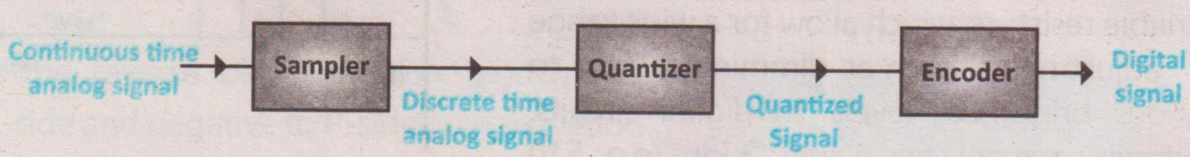


Fig. 19.10: Basic steps of analog-to-digital conversion

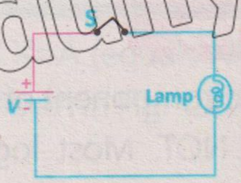
19.3 Boolean Logic

A binary variable has only two possible states, like a switch that is either ON (closed) or OFF (open). These states are represented by 1 and 0 respectively. For example, in a circuit with a battery, lamp, and switch, the state of the switch (open or closed) is the input, and state of the lamp (OFF or ON) is the output. When the switch is open (input = 0), no current flows, and the lamp is OFF i.e; the output is zero. However, when the switch is closed (input = 1), the lamp turns ON and the output is 1 (Fig. 19.11).

> **Brain Teaser**
>
> In Boolean logic, what is the output of an AND gate if one input is 0 and the other is 1?

To understand how inputs affect outputs, George Boole developed Boolean algebra, the foundation of digital electronics and computing, which uses binary values (bits), where each bit is either 0 or 1. A byte is formed using eight bits, which represents data in computers. Boolean algebra is used in ADC which converts analog data (continuous signals) into digital data (discrete binary values). It also forms the basis for designing digital systems.

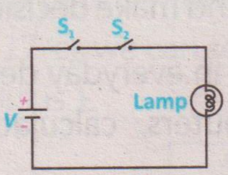
Boolean algebra uses three basic logic operations: AND, OR, and NOT. These operations are implemented using logic gates, which are digital circuits with binary inputs and outputs. A logic gate's output can only be high (1) or low (0), depending on the conditions at its input. For example, AND gate gives an output of 1 only if all its inputs are 1. An OR gate gives an output of 1 if at least one input is 1. A NOT gate inverts the input (1 becomes 0, and 0 becomes 1). AND and OR circuit symbols and truth tables are shown in Fig. 19.12 and Fig. 19.13, respectively.



S	Lamp	State
Open	OFF	0
Closed	ON	1

Fig. 19.11: Binary logic in a circuit (The switch (S) controls the lamp based on boolean logic—Open (0) = OFF, Closed (1) = ON)

In the case of the AND gate, a lamp is connected in series with two switches, S_1 and S_2, along with a battery. In this configuration, the lamp only lights up when both switches are closed, forming a complete path for current to flow. If either switch is open, the current is interrupted, and the lamp remains OFF. This setup models the logic AND operation, where the output is 1 only if both inputs are 1. The circuit, switching combinations (Fig.19.12(a), and truth table are illustrated in Fig. 19.12(b).

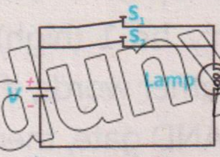


(a)

S_1	S_2	Lamp
Open	Open	OFF
Open	Closed	OFF
Closed	Open	OFF
Closed	Closed	ON

(b)

Fig. 19.12: (a) Circuit representation of AND logic using switches (b) Truth table for AND logic



(a)

S_1	S_2	Lamp
Open	Open	OFF
Open	Closed	ON
Closed	Open	ON
Closed	Closed	ON

(b)

Fig. 19.13: (a) Circuit representation of OR logic using switches (b) Truth table for OR logic

For the OR gate, the lamp is connected in a circuit where switches S_1 and S_2 are placed in parallel (Fig. 19.13-a). In this arrangement, the lamp glows if either or both switches are closed, as current can flow through at least one path. The lamp remains OFF only when both switches are open. This models the logic OR operation, where the output is 1 if any one or both inputs are 1. The complete explanation and truth table for the OR operation are provided in Fig. 19.13(b) .

Tidbit

Tiny circuits called logic gates act like smart switches, making decisions inside our computers, watches, and phones.

These simple logic gates can be combined to perform complex operations, forming the backbone of modern digital systems, from computers to smartphones. By using Boolean algebra and logic gates, we can systematically design circuits that process binary data efficiently and reliably.

19.4 Logic Gates

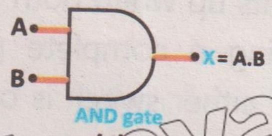
A logic gate is a basic component of digital circuits that performs logical operations like AND, OR, and NOT. Most logic gates have two inputs and one output. However, in the NOT gate, there is only one input and one output. These gates enable digital devices to process binary data and make decisions.

Logic gates are used in everyday devices like smartphones, computers, calculators, and digital watches.

> **Do You Know?**
>
> **The Meaning of Logic Gates**
>
> - A **gate** is a device that performs a basic operation on electrical signals.
> - Gates are combined into **circuits** to perform more complicated tasks.
> - **Logic Gates** are the circuits that are designed to perform these basic logic functions.
> - Actually, the term logic is applied to digital circuits used to implement logic functions.

AND GATE

The AND gate has two inputs. The output of the AND gate will only be 1 (high) if both inputs are 1 (high). In other words, if A and B are two inputs of the AND gate, then output X will be 1 if A=1 and B=1. The logic equation for the AND gate is written as $X=A\cdot B$ (X equals A AND B). The circuit symbol for AND gate and its truth table are shown in Fig. 19.14 (a) and Fig. 19.14 (b), respectively.



(a)

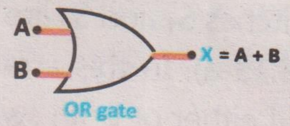
A	B	X = A.B
0	0	0
0	1	0
1	0	0
1	1	1

(b)

Fig. 19.14: (a) The circuit symbol and (b) Truth table for an AND gate

OR GATE

The OR gate has two inputs. The output of OR gate will be 0 (low) if both the inputs are 0 (low). In other words, if A=0 and B=0, then X=0, otherwise X=1. The logic equation for OR gate is written as $X=A+B$ (X equals A OR B). The circuit symbol for OR gate and its truth table are shown in Fig. 19.15 (a) and Fig. 19.15 (b), respectively.



(a)

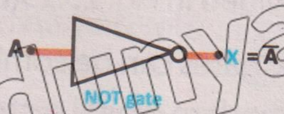
A	B	X = A+B
0	0	0
0	1	1
1	0	1
1	1	1

(b)

Fig. 19.15: (a) The circuit symbol and (b) Truth table for an OR gate

NOT GATE

NOT gate has single input. It is also called an inverter as it inverts the input signal, i.e; if its input is 1, then the output will 0 and vice



(a)

A	X = $\bar{A}$
0	1
1	0

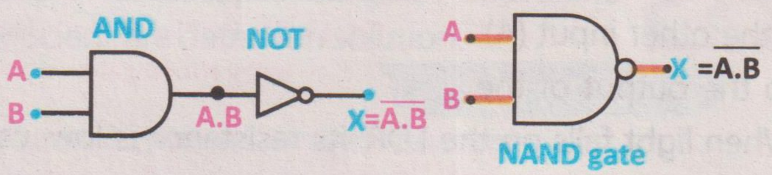
(b)

Fig. 19.16: (a) The circuit symbol and (b) Truth table for NOT gate

versa. The Logic equation for the NOT gate is $X=\overline{A}$ (equals NOT A). The symbol of NOT gate (Fig. 19.16-a) and the truth table is shown in Fig. 19.16 (b).

NAND GATE

A NAND gate is a combination of AND gate and NOT gate. The symbol for a NAND gate is made from an AND gate along with the bubble circle at its output as shown in Fig. 19.17 (b). The logic equation for the NAND gate is written as $X=\overline{A \cdot B}$ (read as X equals NOT A AND B). From truth table (Fig.19.17-c), we can see that the output is 0 when both inputs A and B are 1, otherwise output is 1.



(a) (b)

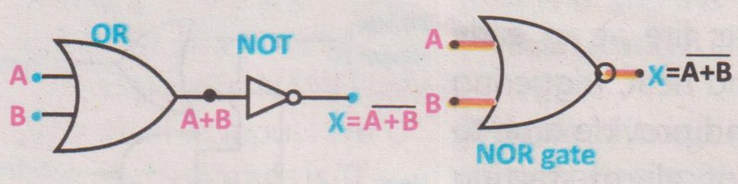
A	B	$X = \overline{A.B}$
0	0	1
0	1	1
1	0	1
1	1	0

(c)

Fig. 19.17 (a,b): The circuit symbol (c) Truth table for NAND gate

NOR GATE

A NOR gate is an OR gate with a NOT gate at its output (Fig. 19.18-a). The symbol for a NOR gate is made from an OR gate with the inversion circle (bubble) at its output as shown in Fig. 19.18 (b). The logic equation for the NOR gate is written as $X=\overline{A+B}$ (read as X equals not A OR B). From truth table (Fig. 19.18.-c), we can see that the output is 1 when both inputs A and B are 0, otherwise output is 0.



(a) (b)

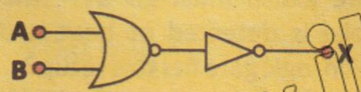
A	B	$X = \overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

(c)

Fig. 19.18 (a,b): The circuit symbol (c) Truth table for NOR gate

Brain Teaser

Show that the circuit given below acts as OR gate.



Brain Teaser

Show that the circuit given below acts as AND gate.

19.5 Applications of Logic Gates

Burglar Alarm

We can create a simple burglar alarm using a single NAND gate, an LDR (Light-Dependent Resistor), a push-button switch (S), and an alarm. The LDR is connected between one input (B) of the NAND gate and the positive terminal of the battery, while the push-button switch (S) is connected to the other input (A). The alarm is connected to the output of the NAND gate (Fig. 19.19). When light falls on the LDR, its resistance is low, causing input B to be high (1). However, if the burglar interrupts the light (e.g., by blocking it), the LDR's resistance becomes high, causing input B to be low (0). Similarly, if the burglar steps on the push-button switch (S), input A becomes low (0). The NAND gate outputs low (0) only when both inputs are high (1); otherwise, it outputs high (1). This means the alarm will sound if either the light is blocked (B = 0), the switch is pressed (A = 0), or both events occur simultaneously. This simple yet effective circuit ensures the alarm is triggered in response to unauthorized entry, making it a practical burglar alarm system.

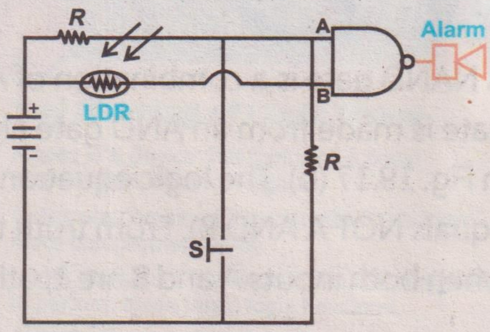


Fig. 19.19: Burglar alarm circuit using NAND gate

Fire Alarm System

A fire alarm system detects fire at an early stage by sensing smoke and heat, triggering an alarm to warn people and provide time to take action. It consists of alarm-starting devices (like smoke detectors and heat sensors), alarm devices (such as sirens), fire control systems (like sprinklers), and power supplies (Fig. 19.20). The alarm can be triggered by sensors such as smoke detectors or heat sensors, which are designed to detect certain levels of smoke or heat that may indicate a fire. While there are advanced and high-cost fire alarm systems available, it is also

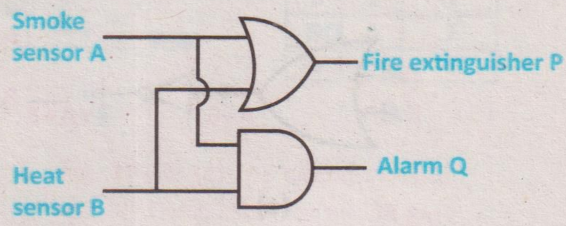


Fig. 19.20: Circuit diagram of fire alarm using basic logic gates

Brain Teaser

A fire alarm must go OFF when either smoke is detected or heat is detected. Which logic gate fits this setup?

possible to make a basic fire alarm using simple components like thermistors, LM358 (Operational amplifier), germanium diodes, LM341 (Voltage regulator), and NE555 (Timer IC). Furthermore, a fire alarm system can be constructed using basic logic gates. For instance, a circuit with logic gates can process inputs from smoke and heat sensors, triggering the alarm when either of the conditions is met, providing an affordable and efficient fire detection solution.

For Your Information

How Fire Alarms Can Save Lives?

1. Early detection saves lives
2. Fire alarms can detect fires before they become large
3. Fire alarms can alert the authorities
4. Fire alarms can be connected to a monitoring service
5. There are different types of fire alarms
6. Fire alarms should be tested regularly

EXERCISE

A. Multiple Choice Questions

Tick(✓) the correct answer.

19.1 A diode allows current to flow in:
(a) both directions (b) neither direction
(c) one direction only (d) random directions

19.2 What is the primary function of a light-emitting diode?
(a) To block current in both directions
(b) To emit light when current passes in one direction
(c) To amplify electrical signals
(d) To convert light into electrical energy

19.3 The output of a two inputs NOR gate is '1', 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'

19.4 The output of a NAND gate is '0', 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'

19.5 How many bits make up a byte in Boolean logic?
(a) 2 (b) 4 (c) 6 (d) 8

B. Short Answer Questions

19.1 What is the function of a semiconductor diode?

19.2 What happens when a diode is forward biased?

19.3 What is the function of an LED?

19.4 Why does an LED emit light when current passes through it?

19.5 What does an analog-to-digital converter (ADC) do?

19.6 What is the difference between analog and digital signals?
19.7 What is Boolean logic in digital electronics?
19.8 What does a NOT gate do in a digital circuit?
19.9 What is the role of an AND gate in digital circuits?

C. Constructed Response Questions

19.1 Why would a diode be damaged if it is connected in reverse bias with a very high voltage? What does this tell us about the diode's physical limits?
19.2 What makes an LED glow brighter or dimmer depending on the voltage applied? How is this property used in adjustable display brightness?
19.3 Why are digital systems more reliable than analog systems when transmitting signals over long distances?
19.4 Why is the NOT gate also called an inverter, and how can such a simple function have a major role in digital decision-making?
19.5 Why would a security system use NAND gates instead of OR or AND gates for certain logical conditions?

D. Comprehensive Questions

19.1 Explain how the depletion region of a diode changes in forward and reverse bias. What effect does this have on current flow?
19.2 Describe how an LED produces light. Also explain how the type of semiconductor material affects the colour of the light.
19.3 What is Boolean logic? Discuss its importance in solving complex digital problems with examples.
19.4 What are logic gates? Describe the working of NAND and OR gates with the help of truth tables and circuit symbols.
19.5 How does a NOR gate work, and how can it be used to build other basic logic gates?
19.6 How can a burglar alarm be designed using a NAND gate and an LDR? Explain.