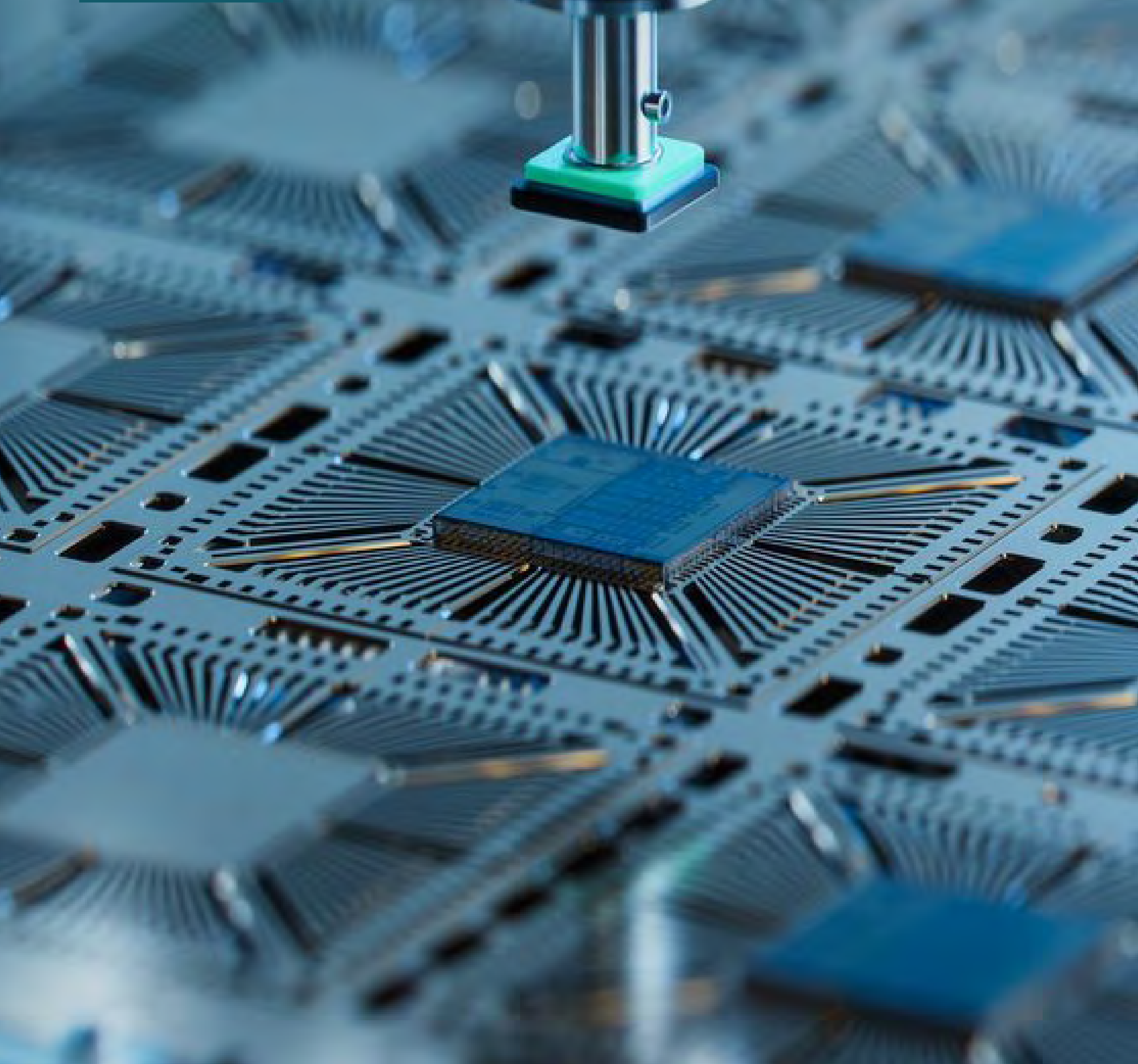
Physics Year 1

SECTION

7

SEMI CONDUCTORS, TRANSDUCERS AND THEIR APPLICATIONS



ELECTROMAGNETISM

Analogue Electronics

INTRODUCTION

In this section, you will learn about important electronic components and how they work. The section starts with lessons on semiconductors and PN junction diodes, which are special materials and devices that help control electrical currents in gadgets. Next, you will explore Light-Emitting Diodes (LEDs), which are used in things like lights and screens because they produce bright light when electricity flows through them. Zener diodes, which help keep the voltage steady in electrical circuits will be discussed. Additionally, you will see how temperature changes can affect resistance, which is how much a material resists the flow of electricity. This helps us understand how different materials behave in various conditions. You will study the different transducers, which are devices that change one type of energy, like light or sound, into electrical signals. Lastly, you will learn about the Bipolar Junction Transistor (BJT), a component used to amplify electrical signals, and transistor biasing, which is important for making sure the transistor works properly.

By the end of this section, you will be able to:

- Describe the formation of the two types of semiconductors: n-type and p-type.
- Describe the basic structure and applications of the PN junction diodes in reverse and a forward-biased circuit.
- Analyse the benefits of LEDs and I-V characteristics of Zener diodes and their applications.
- Explain the effect of temperature changes on resistance using a thermistor, light- dependent resistor (LDR), infra-red diode and the microphone and analyse the characteristic graphs of thermistors and LDRs.
- Explain the terminologies “input” and “output” of a transducer with examples.

- Describe the processes of the following transducers: microphone, loudspeaker, buzzer, low voltage DC motor, electromagnetic relays and infra-red diodes.
- Describe the construction and action of the bipolar junction transistor.
- Describe transistor biasing.
- Describe the various transistor configurations and use of an NPN transistor as a small signal amplifier.

KEY IDEAS

- Semiconductors and PN junction diodes help control the flow of electricity.
- Light Emitting Diodes (LEDs) turn electricity into light.
- Zener diodes help regulate voltage.
- Temperature changes can affect how materials resist electricity.
- Transducers are devices that change one type of energy into another.
- Bipolar Junction Transistors (BJTs) are used for amplifying signals. They must be set up properly with transistor biasing.

SEMICONDUCTOR AND DIODES

N-Type And P-Type Semiconductors

A semiconductor is a material that can conduct electricity better than an insulator but not as well as a conductor (such as a metal). The most common semiconductor materials are silicon (Si), germanium (Ge), and a compound gallium arsenide (GaAs).

The diagram below shows the structure of a pure silicon semiconductor.

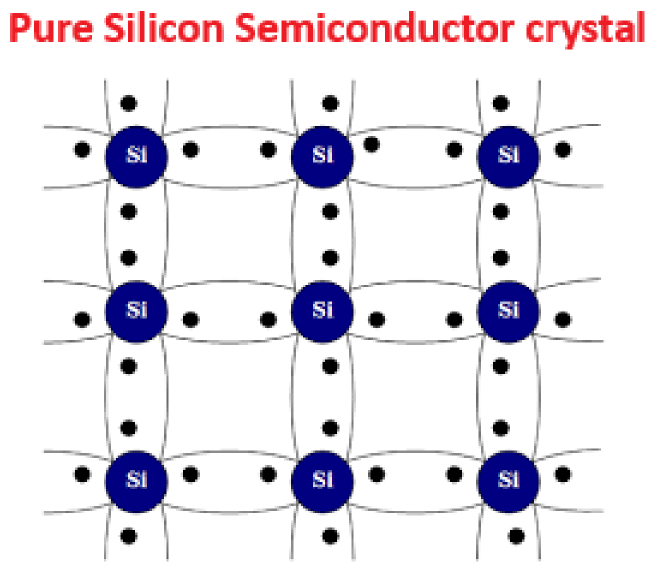


Fig 7.1: Lattice structure of pure silicon semiconductor

Semiconductors are special because we can change how well they conduct electricity by adding small amounts of other materials called **impurities** to them. The impurity can be atoms with five electrons in the outermost shell called **pentavalent** atoms e.g. phosphorus or atoms with three electrons in the outermost shell call **trivalent** atoms e.g. boron.

There are two types of semiconductors:

i. **Intrinsic** or pure semiconductors

An intrinsic semiconductor is a semiconductor in its pure or natural state. In this pure form, the semiconductor has a balanced number of electrons and holes (empty spaces that act like positive charges).

ii. **Extrinsic** semiconductors

An extrinsic semiconductor is a type of semiconductor that has a small amount of impurity added to it. This impurity helps the semiconductor conduct electricity more effectively. There are two types of **extrinsic** semiconductors:

- **N-type** semiconductors
- **P-type** semiconductors

N-type semiconductors:

- "N" stands for negative.
- This type is made by adding a pentavalent atom (phosphorus) that gives the semiconductor extra electrons (which are negatively charged particles).
- These extra electrons allow the semiconductor to conduct electricity better because electrons can move and carry an electric current.

The diagram below shows the structure of N-type semiconductor doped with pentavalent atom

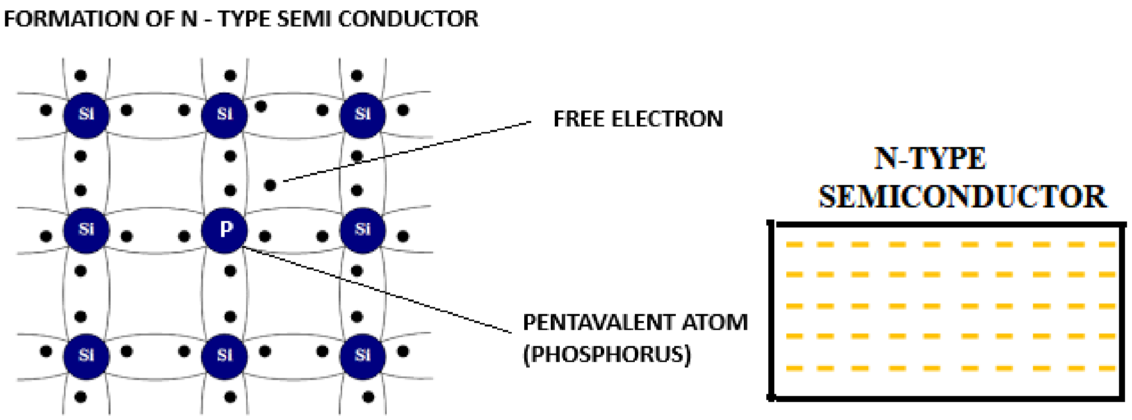


Fig 7.2: Formation of N-Type semiconductor by doping silicon with a pentavalent impurity

P-type semiconductors:

- "P" stands for positive.
- This type is made by adding trivalent atom (boron). This creates "holes" in the semiconductor.
- A hole is a spot where an electron is missing, and it acts like a positive charge.
- Electricity can flow because electrons can move into these holes causing a flow of electric current.

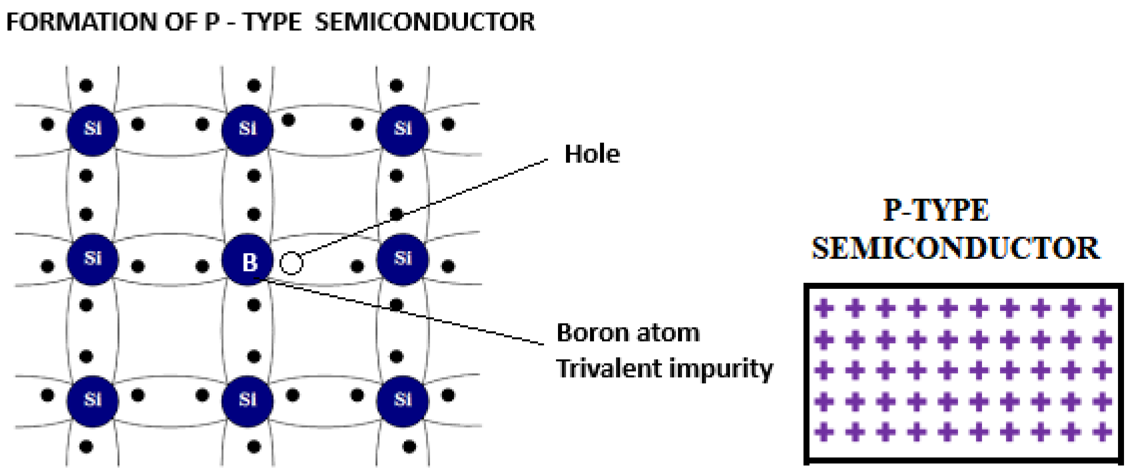


Fig 7.3: Formation of P-Type semiconductor by doping silicon with a trivalent impurity

Activity 7.1: Exploring the effects of doping in semiconductors

1. Identify the difference between n-type and p-type semiconductors. Describe the main charge carriers in each type and how they affect the semiconductor's ability to conduct electricity.
2. Explain what happens during the doping process of a semiconductor. How does adding a dopant like phosphorus or boron change the properties of the semiconductor?

Activity 7.2: Illustrating electron and hole movement in semiconductors

Produce a stop-motion animation, video or model demonstrating and explaining the movement of electrons or holes in N- and P- type semiconductors.

Formation of a Diode

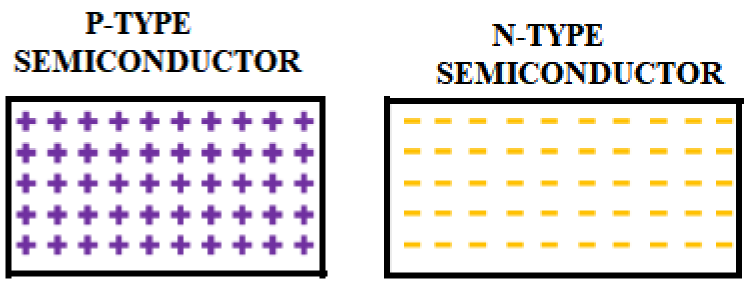


Fig 7.4: P-type semiconductor and N-type semiconductor

Consider a piece of P-type semiconductor joined together with a piece of N-type semiconductor. Discuss with your neighbour the subsequent movement of the charge carriers (electrons and holes) between the two materials. Then, read ahead to find out more!

When a P-type material is joined with an N-type material, they form a **PN junction**, also known as a **diode**.

A diode is an electronic component that allows current to flow in **only one direction.** It has two terminals, the anode (positive) and the cathode (negative).

A P-type material contains holes (empty spaces where electrons can move), while an N-type material has free electrons. Since opposite charges attract, some holes from the P-side move toward the N-side, and some electrons from the N-side move toward the P-side.

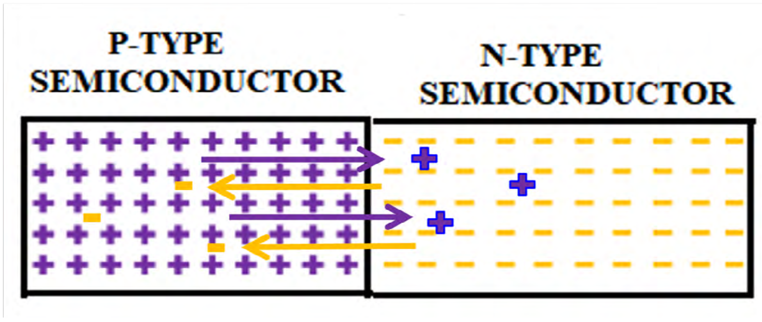


Fig 7.5: P-N Junction formation

As these charges meet at the junction, they neutralise each other, forming positive and negative ions. This creates a charged region at the junction, known as the **depletion region/layer**.

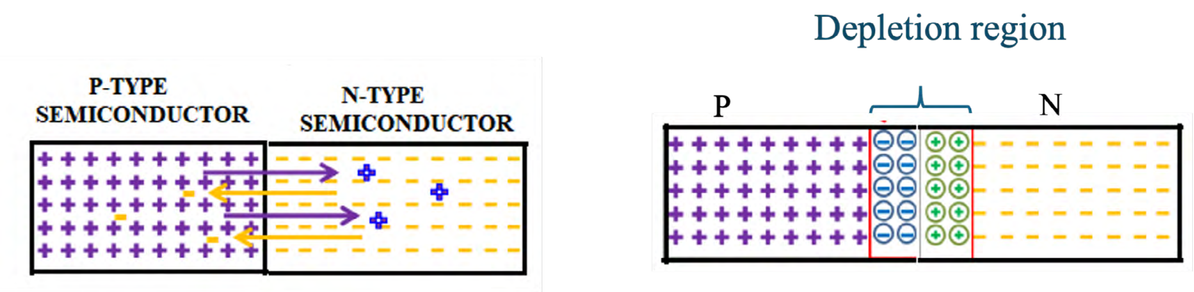


Fig 7.6: Charge carrier diffusion in a P-N Junction

The separation of positive and negative ions in the depletion region forms a potential barrier, which prevents further movement of charge carriers across the junction.

Diodes can be used in two different ways depending on how they are connected in a circuit:

1. Forward Bias
2. Reverse Bias

Forward Bias

In forward bias, the positive terminal of the power source (like a battery) is connected to the anode (the positive side of the diode), and the negative terminal is connected to the cathode (the negative side of the diode).

In forward bias, the depletion layer becomes thinner, **allowing current to flow**.

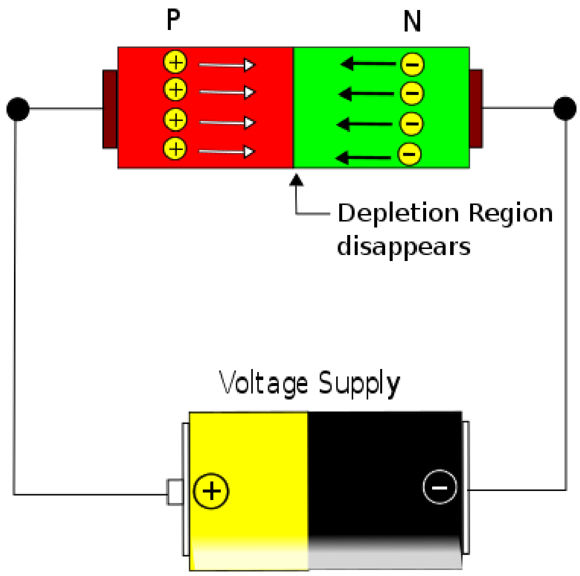


Fig 7.7: Forward Bias Circuit Diagram:

Reverse Bias

In reverse bias, the positive terminal of the power source is connected to the cathode (the negative side of the diode), and the negative terminal is connected to the anode (the positive side of the diode).

In reverse bias, the depletion layer becomes wider, blocking the flow of current.

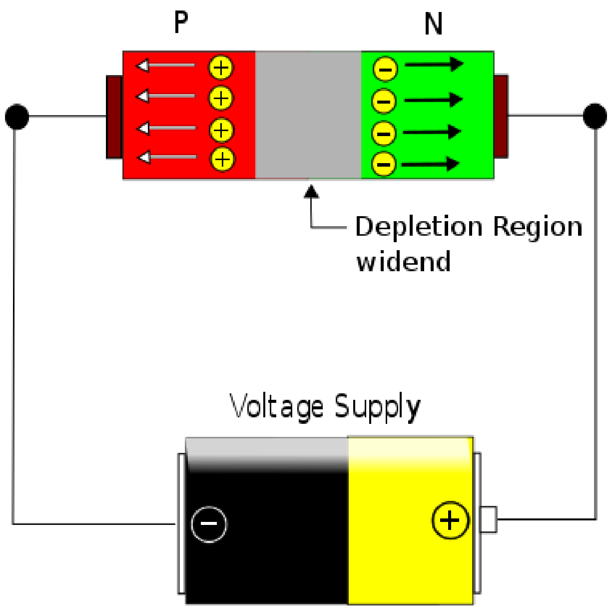


Fig 7.8: Reverse Bias Circuit Diagram

An LED is a Light Emitting Diode. This means that it is a diode which emits light when connected in the forward bias position, indicating that current is flowing in the circuit.

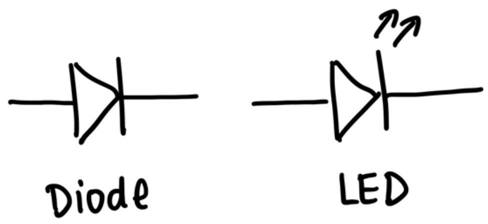


Fig 7.9: Symbol for Diode and LED

The circuit symbols above are for a diode and an LED. Note that the triangle can be considered an arrow pointing from the P-type semiconductor (anode) to the N-type (cathode). Therefore, when in the forward bias position, the arrow points 'with' the flow of current.

Activity 7.3: Exploring semiconductor applications in electronic devices

Describe a simple electronic device that uses both n-type and p-type semiconductors. How do these semiconductors work together in the device?

Activity 7.4 Investigating the behaviour of a diode in a forward bias and reverse bias connection

Note: In the absence of equipment, observe the behaviour of an LED using the JavaLab simulation below

Materials needed:

- LED
- Small battery (1.5V)
- Wires
- Resistor (optional)
- Switch

Procedure:

1. Connect the positive terminal of the battery to the anode (positive side) of the LED and the negative terminal of the battery to the cathode (negative side) of the LED.
2. Turn on the switch and observe the behaviour of the LED. Discuss your observations with a friend.
3. Reverse the connections: connect the positive terminal of the battery to the cathode (negative side) of the LED and the negative terminal of the battery to the anode (positive side) of the LED.
4. Turn on the switch again and observe the behaviour of the LED. Discuss your observations with a friend.

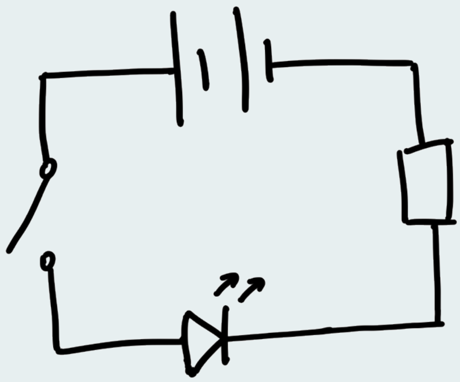


Fig 7.10: schematic of the experimental setup

Extended Activity

1. Add the following components into your circuit:
   - an ammeter in series with the LED
   - a voltmeter in parallel with the LED
   - a variable resistor in series with the LED
2. Starting at zero, slowly increase the voltage across the LED using the variable resistor. Record the current reading after every increase of 0.1V and record the results in a table.
3. Reverse the direction of the current and repeat the experiment.
4. Plot a graph of your results and describe the pattern shown. Identify the 'threshold voltage' of the LED and label this onto your graph.

Discussion questions

1. What did you observe when the positive terminal of the battery was connected to the anode and the negative terminal to the cathode of the diode? Why do you think the diode behaved this way?
2. What happened when the battery terminals were reversed, with the positive terminal connected to the cathode and the negative terminal to the anode? How did this affect the diode's behaviour?
3. How does the diode's behaviour in forward bias and reverse bias help explain its role in electronic circuits? Can you think of practical applications where this characteristic is useful?
4. Based on your observations, how can you determine if a diode is functioning correctly? What signs indicate that the diode might be damaged or malfunctioning?

Activity 7.5: Exploring the semiconductors in solar cells: N-type and P-type

Investigate the role of n-type and p-type semiconductors in the functioning of a solar cell. Create a presentation or poster explaining how they work together to generate electricity.

LEDS, ZENER DIODES, THERMISTORS AND LDRS

In this learning area, we will delve into the fascinating world of Light Emitting and Zener diodes. We will be exploring their properties, characteristics, and applications.

Activity 7.6: Exploring Diodes: LEDs and Zener Diodes

We have briefly discussed LEDs already. Fill in what you know about them in the table below. Also, include anything you already know about Zener diodes!

Table 7.1: Table to fill diode description and uses

Diodes	Description	Uses
LED		
Zener diodes		

Activity 7.7: Comparison of LEDs and Incandescent Bulbs

Materials needed:

- LED bulb (e.g., 9W)

Fig. 7.11: Red, Green, and Filament LEDs

- Incandescent bulb (e.g., 60W)
- Ammeter and voltmeter *or* multimeter
- Power source (e.g., power pack, battery pack)
- Light meter (optional)
- Variable resistor

Procedure:

1. Set up the experiment by connecting the LED and incandescent bulbs to separate power sources (see diagrams below)

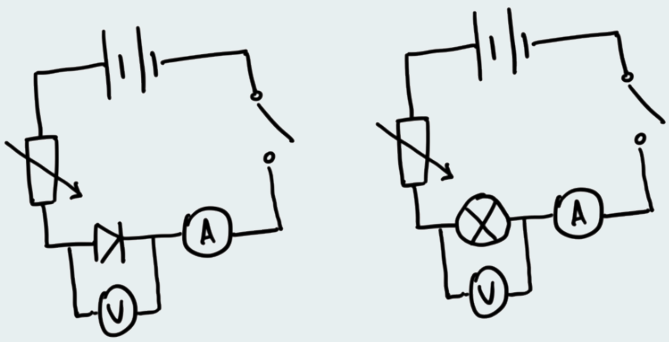


Fig. 7.12: schematic of the experimental setup

2. Slide the variable resistors to give the lowest voltage reading. Measure and record the initial voltage and current.
3. Measure and record the brightness of each bulb using a light meter (if available). Otherwise, describe the brightness of the LED versus that of the incandescent bulb.

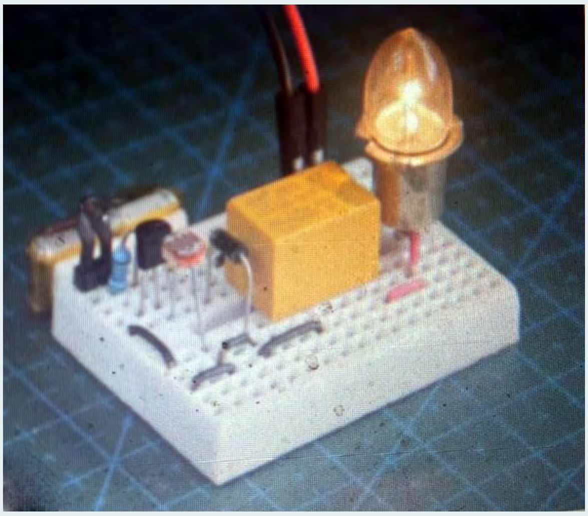


Fig 7.13: Image of the setup

4. Gradually increase the voltage and measure the corresponding current and brightness readings.
5. Calculate the power consumption of each bulb for each row in your table using the formula *Power (W) = Current (A) x Voltage (V)*.
6. Analyse the data and compare the brightness and power consumption of the two bulbs.

Discuss with your friend:

- What are the energy conservation implications of using LEDs rather than incandescent lights?

The structure of LEDs

In illuminated LEDs, the P-type and N-type regions are forward-biased. Although they operate like any other forward-biased junction diode, the material they are composed of differentiates them from ordinary ones.

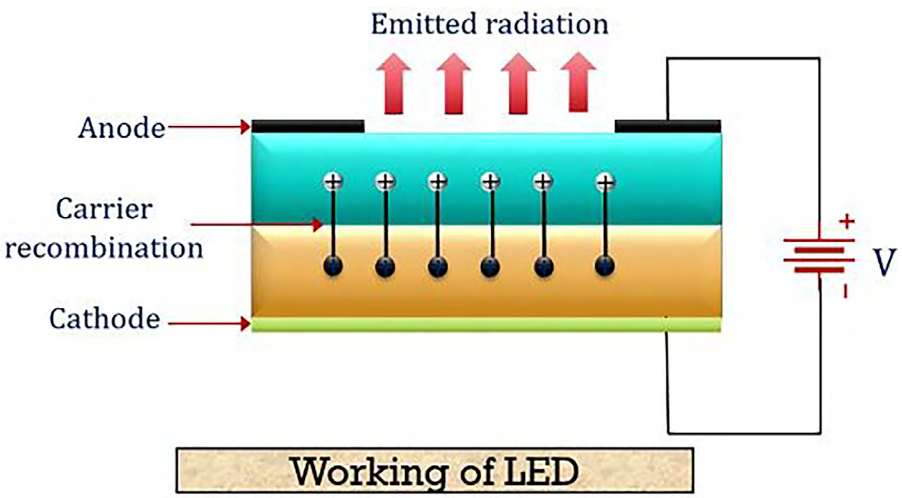


Fig 7.14: LED Operation: Carrier Recombination and Light Emission

- When an LED is forward biased (positive voltage applied to the p-side and negative to the n-side), electrons from the n-region and holes from the p-region move toward the junction.
- At the junction, electrons recombine with holes. During this recombination, energy is released in the form of photons, which produces visible light.

The colour of the emitted light depends on the energy band-gap of the semiconductor material used. LEDs can emit red, green, blue, and other colours.

LEDs are highly energy-efficient and are used in various applications like indicator lights, displays, and lighting systems

Activity 7.8: Identifying LED applications in everyday life

List as many uses of LEDs as possible; look around you for inspiration! Are there any LEDs used in your classroom? On the road? In shops or your home? ***See Annex 7.4 for further information on LEDs.***

Activity 7.9: Investigating Zener Diodes

Before we continue to discuss how Zener diodes operate, let us first observe their behaviour in a simple circuit:

Materials needed:

- Breadboard (optional)
- Zener diode (e.g., 5.1V)
- Variable resistor
- 33 Ohm resistor
- DC power source (e.g., 9V battery, 6V battery)
- Multimeter *or* voltmeter
- Jumper wires

Procedure:

1. Build the circuit shown below.

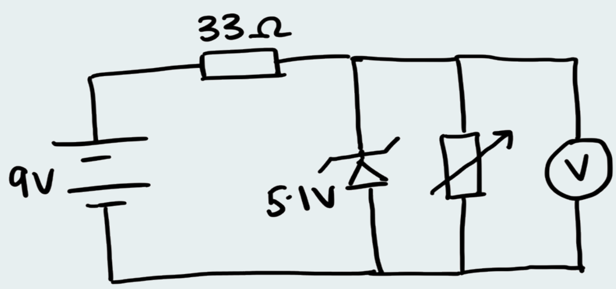


Fig 7.15: schematic of the experimental setup

2. Measure the voltage across the load (variable resistor) when it is in different positions.
3. Observe how the Zener diode maintains a constant output voltage despite variations in the load.
4. Replace the 9V battery with a 6V battery.
5. Observe how the Zener diode maintains a constant output voltage despite variations in the supply voltage.

Discuss with your friend:

- What might be some advantages of using a Zener diode in a power supply circuit?

Zener diodes

A Zener diode is also a p-n junction semiconductor, but it is specifically designed to operate in reverse bias. It has a heavily doped p and n-region, which allows it to conduct in reverse mode at a precise breakdown voltage. Zener diodes are encased in glass or plastic to protect them from damage and are identified by their reverse breakdown voltage rating.

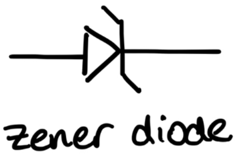


Fig 7.16: symbol of a Zener diode:

The structure of Zener diodes

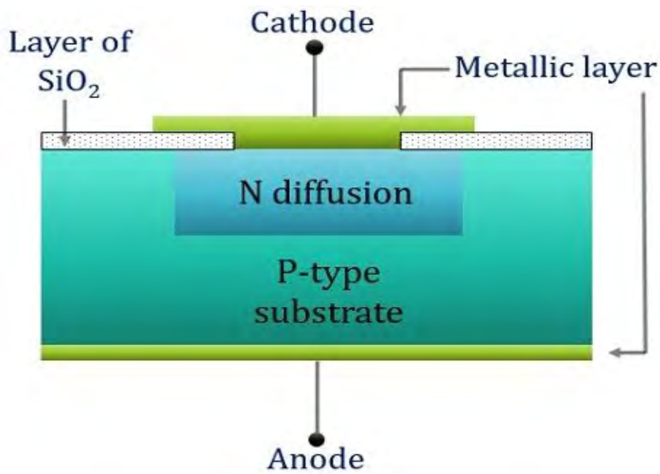


Fig 7.17: Structure of Zener diode

- In forward bias, a Zener diode behaves like a regular diode, allowing current to flow when the p-side is positive.
- In reverse bias, when the voltage applied to the n-side exceeds a certain threshold (called the Zener breakdown voltage), the diode allows current to flow in reverse.
- The Zener diode is designed to maintain a stable voltage across itself when in reverse breakdown mode, even as the current varies. This makes it useful for voltage regulation.
- In this mode, the diode does not get damaged due to its construction, and it can regulate voltage in power supplies or act as a voltage reference in circuits.

The I-V characteristic curve of a Zener diode:

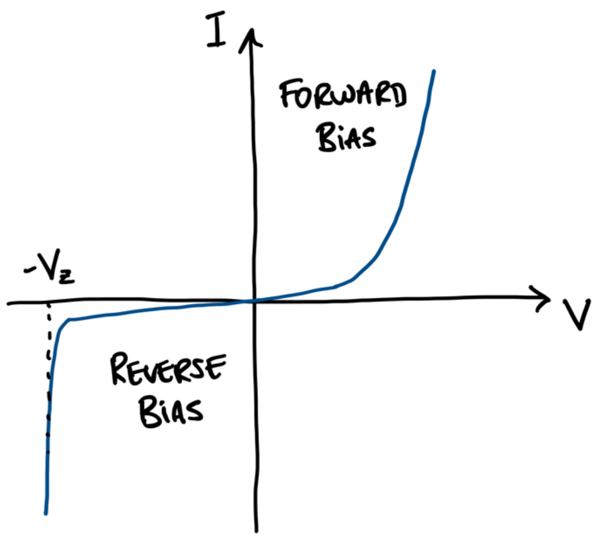


Fig 7.18: I-V characteristics of Zener diode

- In the forward bias region, the diode's behaviour resembles that of a standard diode, as observed in the curve.
- In the reverse bias condition, a small reverse current flows due to minority carriers. As the reverse voltage increases, the current also rises.

The Zener voltage (Vz) is the specific reverse voltage at which the diode conducts significantly in reverse. This voltage can be precisely controlled during manufacturing.

Activity 7.10: Exploring the applications of Zener diodes

List as many potential uses for Zener diodes as you can think of. ***See Annex 7.4 for further information about Zener diodes.***

Temperature dependency in other circuit components

Temperature changes can significantly affect the resistance of various electronic components, including thermistors, light-dependent resistors (LDRs), infrared diodes, and microphones. Here's how each component reacts to temperature variations:

Table 7.2: Circuit components and their effect on temperature

Component	Effect of Temperature
Thermistor	As temperature increases, the resistance of an NTC thermistor decreases. Conversely, as temperature decreases, resistance increases. This property makes thermistors useful for temperature sensing and compensation in circuits.
LDR	While LDRs primarily respond to light, temperature can also affect their resistance. Higher temperatures can lead to decreased resistance due to increased thermal energy, causing more charge carriers to be available. This can result in variations in sensitivity and response time.
Infrared diode (an LED which emits in the IR region)	The resistance of the infrared diode (when reverse-biased) can change with temperature. As temperature increases, the diode's forward voltage drops decrease, which can affect how it operates in a circuit. This change can influence the intensity of the emitted light and the diode's efficiency.
Microphone	The resistance in the microphone can change with temperature, affecting sensitivity and output. In electret microphones, temperature changes can affect the diaphragm material and the electret charge, leading to variations in the electrical signal produced in response to sound.

Activity 7.11: Investigating the environmental dependency of thermistors and LDRs

Materials needed:

- Connecting wires
- Battery (e.g., 6V)
- Ammeter and voltmeter or multimeter
- Thermistor
- LDR
- Hot water source (e.g. kettle)
- Cold water source (e.g. kitchen tap)
- Beaker or cup
- Thermometer
- Flashlight
- Metre ruler

Procedure:

1. Connect the circuit as shown in the diagram, first with the **thermistor** in the place of component X.
2. Place the thermistor into cold or room-temperature water. Record the temperature, the current reading and the voltage reading in a table.
3. Increase the temperature of the water by adding hot water to it. Repeat the same readings as above.
4. Continue to increase the temperature of the water and take readings until the hottest temperature is reached (e.g., water directly from a boiled kettle). Ensure that in total you have at least 6 different temperatures in your table of results.
5. Repeat the experiment but this time with an LDR in the place of component X. Instead of varying the temperature, vary the brightness of the light incident on the LDR by changing the distance between it and the illuminated flashlight. Record the distance between the LDR and flashlight, the current and the voltage into a table. Ensure that in total you have at least 6 different distances in your table of results.

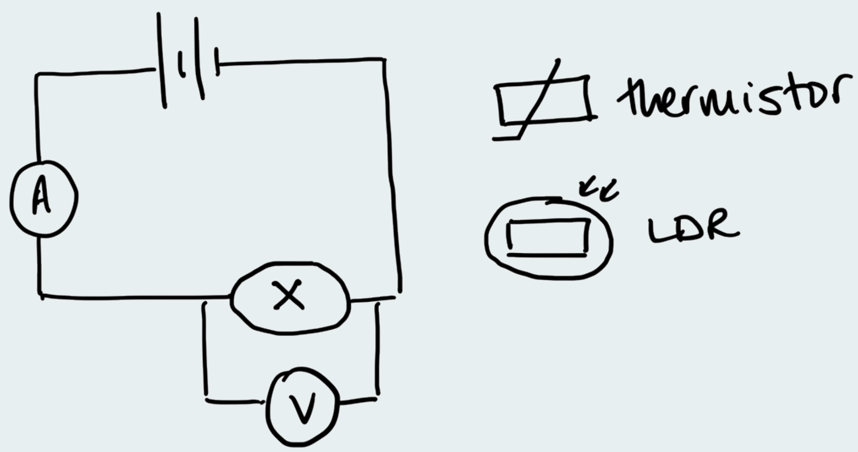


Fig 7.19: schematic of the experimental setup

Analysis:

Plot a graph of your results; for the thermistor, you should plot the temperature on the x-axis and resistance on the y-axis. For the LDR you should plot the distance on the x-axis and the resistance on the y-axis.

Discussion questions:

What do your graphs tell you about the dependency of the resistance of a thermistor on temperature? What do they tell you about the dependency of the resistance on an LDR on brightness?

Thermistors' Temperature Dependency

Types of Thermistor:

1. NTC (Negative Temperature Coefficient): The most common type, where resistance decreases as temperature increases.
2. PTC (Positive Temperature Coefficient): Resistance increases with an increase in temperature.

The steepness of the curve indicates the sensitivity of the thermistor. A steeper curve means a more significant change in resistance for a small temperature change.

LDRs' Brightness Dependency

- High Resistance in Darkness: At low light levels (dark conditions), the resistance of the LDR is high, often in the megaohms (MΩ) range.

- Low Resistance in Light: As light intensity increases, the resistance drops significantly, often to a few hundred ohms or less in bright light.

The steepness of the curve indicates sensitivity. A steeper slope means that small changes in light intensity lead to significant changes in resistance.

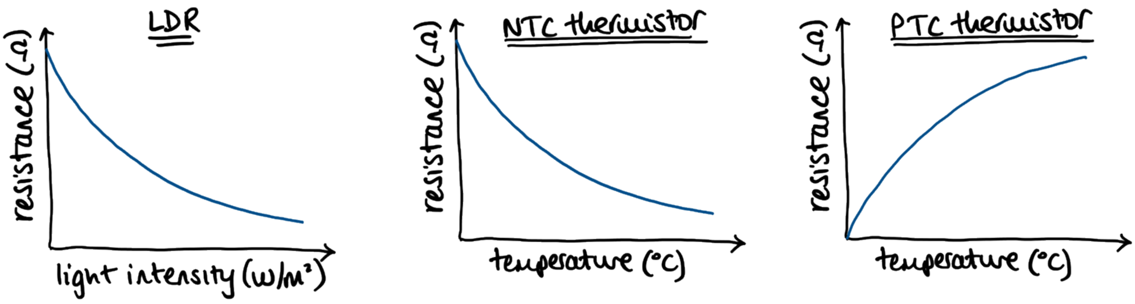


Fig 7.20: Thermistor and LDR characteristic curves

Activity 7.12: Analysing Thermistors in Temperature-Sensing Circuits

1. A thermistor is used in a voltage divider circuit in series with a fixed resistor of 1000 Ohms. At 20 degrees Celsius, the thermistor has a resistance of 500 Ohms. At 80 degrees Celsius, it has a resistance of 50 Ohms. What is the range of output voltages of the thermistor that can be achieved across this temperature range if the input voltage is 5V?
2. A thermistor has a resistance of 1000 Ohms at 25 degrees Celsius. Its resistance coefficient is -3.5% per degree Celsius. What is its resistance at 50 degrees Celsius?
3. A thermistor is placed in series with a fixed resistor. A buzzer is placed in parallel with the fixed resistor. If the buzzer is required to sound if the temperature of the surroundings increases, what kind of thermistor should be used; NTC or PTC? Justify your answer.

Activity 7.13: Researching real-world applications of Thermistors and LDRs

Research and present to your peers a real-world application of thermistors or LDRs. Explain the importance of your chosen component in your chosen application and highlight any important considerations in the design process of your device.

TRANSDUCERS

Transducers are instrumental devices that convert one form of energy or physical quantity into another, by taking an input signal (like light, sound, temperature, or pressure) from the environment and processing it into a more useful output in a different form.

Think about the microphone you use for entertainment. When you speak into it, the sound waves from your voice are converted into electrical signals. Therefore, a microphone is a transducer. These signals travel through wires and can be amplified or recorded, and when they reach a loudspeaker, they are converted back into sound, filling the room with music. Therefore, a loudspeaker is also a transducer.

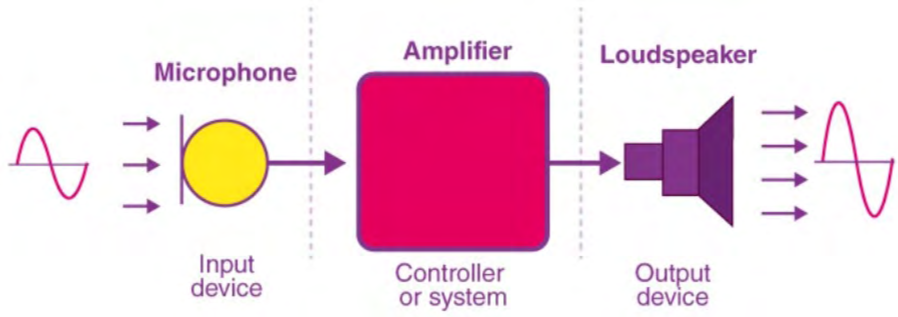


Fig 7.21: Simple Input/Output System using Sound Transducers

Transducers are everywhere—your TV remote uses infrared diodes to send signals across the room, changing the channel at the press of a button. In your kitchen, the thermometer measures temperature, while motion sensors automatically open doors in hotels and conference halls. Even your phone's touchscreen relies on transducers to detect touch and respond to your commands.

These devices are also behind more advanced technologies, like ultrasound machines that scan internal organs. From automation to communication, transducers play a vital role in making our world more efficient and interconnected. Imagine the possibilities—what new inventions could you create using transducers to improve life around your home or workplace? The potential is limitless!

Activity 7.14: Exploring input, process, and output in transducers

Fill in the table below with the input signal and output signal for each transducer. If you know anything about the processes that they use to convert the energies, you could fill this in, too.

Terminologies:

- **Input of a Transducer**: Refers to the physical quantity (e.g., sound, temperature, light) that is sensed or detected by the transducer. The input is typically non-electrical. **Example**: In a microphone, the input is sound waves.
- **Output of a Transducer**: Refers to the converted signal, usually in electrical form, which is the result of the input being processed by the transducer. **Example**: In a microphone, the output is an electrical signal representing the sound.

Table 7.3: Table to fill input, process and output in some transducers

Transducer	Input	Process	Output
Microphone			
Loudspeaker			
Buzzer			
Low Voltage DC Motor			
Electromagnetic Relay			
Infra-red Diode (IR LED)			
Piezoelectric Sensor			
Thermocouple			

Each transducer is specialised for converting specific types of energy and is widely used in industries such as healthcare, automotive, consumer electronics, and environmental monitoring.

Activity 7.15: Identifying applications of different transducers

For each of the transducers in the table above, give one useful application.

Modelling and Investigating Different Transducers and their Applications

Activity 7.16: Create a Simple Loudspeaker

Materials needed:

- Small magnet(s)
- Paper or Styrofoam cup
- .Copper wire (for coils)
- Tape or glue
- Scissors
- Source of audio signal (e.g. mobile phone, laptop)
- Connecting wires including audio jack

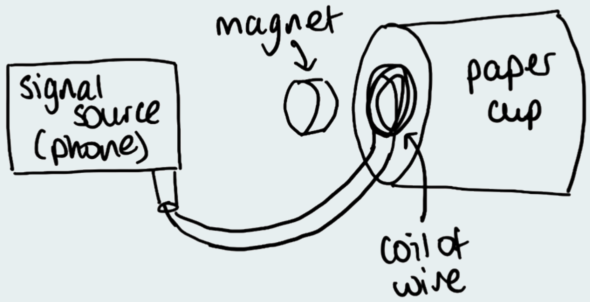


Fig 7.22: DIY speaker with paper cup, magnet, and coil

Procedure:

1. Use the plastic cup to build a basic loudspeaker.
2. Attach a coil of wire to the outside of the cup at the bottom, with the wire leads exposed.
3. Place a small magnet beside the coil (without touching it).
4. Connect the exposed wires of the loudspeaker model to the audio source.

Discussion:

Discuss the energy conversion process in this piece of equipment. How does this work? Research the physics behind this and explain it to your peer.

Activity 7.17: Create a 'streetlight' model

Materials needed:

- LDR
- LED
- Connecting wires
- Battery (up to 6V)
- Fixed resistor (10kOhms)
- Light source (e.g., lamp)
- Transistor

Procedure:

1. Build the circuit as shown below:

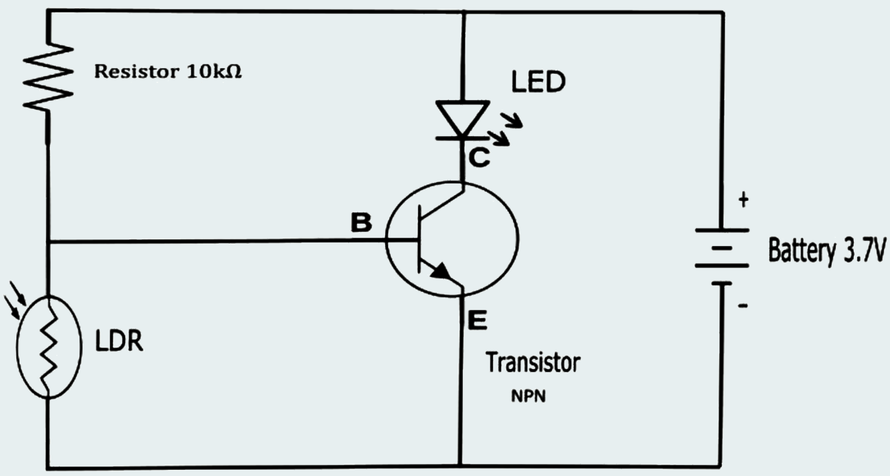


Fig 7.23: schematic of the experimental setup

2. Vary the brightness of the light on the LDR to find the limiting position of the light source where the LED turns on and off.

Discussion:

Discuss the energy conversion process in this piece of equipment. How does this work? Research the physics behind this and explain it to your peer.

Activity 7.18: Exploring Electromechanical Processes in Buzzers and DC Motors

Materials needed:

- Buzzers
- Simple DC motors
- Screwdrivers or small tools for disassembly
- Power source (e.g., batteries)
- Some connecting wires

Disassembly of Buzzer and DC Motor:

1. Obtain a buzzer and a DC motor.
2. Following a guideline, disassemble the buzzer and motor using screwdrivers, noting key components such as coils, magnets, and diaphragms.
3. Document and sketch the internal structure.

Testing and Mapping Energy Conversion:

4. Using a power source, connect the buzzer and observe how electrical energy is transformed into sound.
5. Connect the DC motor to the battery, observing the conversion of electrical energy into mechanical rotation.

Discussion:

Discuss the energy conversion process in these pieces of equipment. How does this work? Research the physics behind this and explain it to your peer.

Discuss how these mechanisms are used in everyday devices (e.g., doorbells, electric fans).

Table 7.4: Table to complete observations made during **Activity 7.18**

Device	*Input Energy Form*	*Output Energy Form*	*Key Components Observed*	*Practical Application*	*Notes/ Observations*
Buzzer		Sound Energy		Doorbells, Alarms	Sound produced when current flows
DC Motor			Coil, Magnets, Armature		

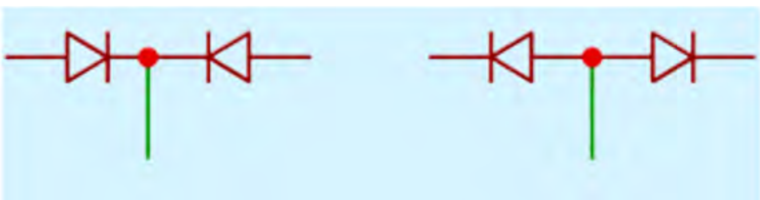
Activity 7.19: Planning transducer circuits to solve problems

1. SONABEL, the power utility of Burkina Faso, manages the Bagre Dam. When there is a high inflow of water into the dam, they spill, and consequently, the water levels in the White Volta also increase. Outline a plan for a transducer system to monitor water levels at the White Volta River rapids near Gambaga in the North East Region of Ghana as part of a flood warning and prevention system for the Volta River Authority of Ghana. Describe the type of transducer you would use, how it would function, and the benefits of your solution.
2. The Department of Urban Roads seeks to implement a real-time traffic monitoring and response system at some traffic intersections in Ghana. As part of the plan, an intelligent traffic control system will be installed to redistribute traffic efficiently, unlike the current fixed-time system. Outline a circuit that uses an electromagnetic relay as a simple switch for safely controlling red yellow-green signals, which work on the higher power supply. Describe the components you would use and their configuration.

TRANSISTORS

A transistor is an electronic component that controls the flow of electricity in a circuit. It can act like a switch or an amplifier, helping to manage and increase electrical signals.

After learning about diodes, which consist of a single PN junction, you can now move on to learn about a more complex component called the **transistor**. By connecting two PN junctions together, you will form a **Bipolar Junction Transistor (BJT).** The diagrams provided below show how these two PN junctions combine to create the transistor, which can amplify and control electrical signals in circuits.



(a) Two PN Junction diodes connected

(b) Different shapes of Bipolar Junction Transistors

Fig 7.24: Transistors

The **Bipolar Junction Transistor (BJT)** is made by joining two types of semiconductor materials, called P-type and N-type. These materials are arranged in layers to form either a PNP or NPN structure as shown in the diagram below.

You can see in the diagram below that in a PNP transistor, two P-type layers surround an N-type layer, while in an NPN transistor, two N-type layers surround a P-type layer. This structure allows the BJT to control the flow of current in a circuit.

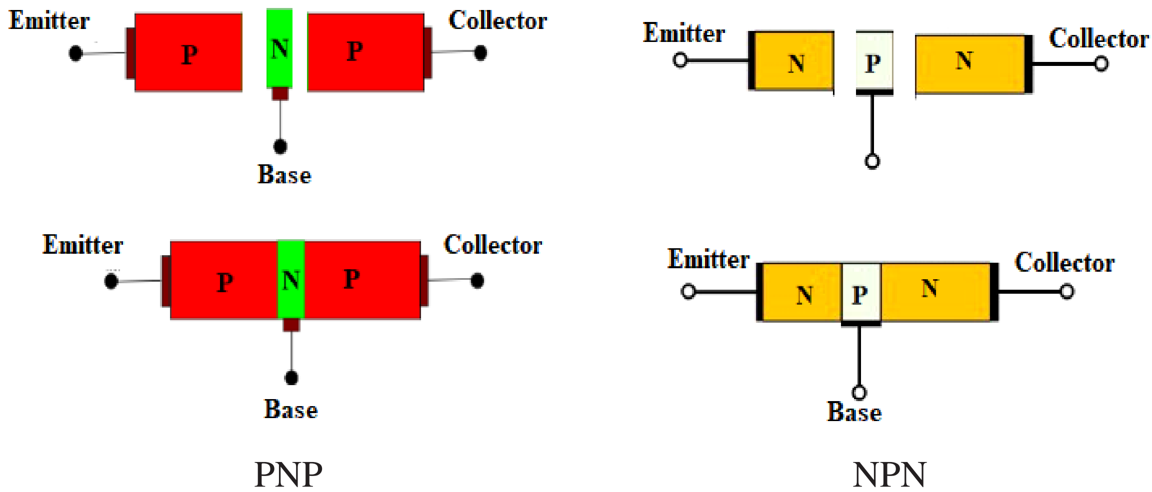


Fig 7.25: PNP and NPN transistors

Bipolar junction transistor (BJT)

The Bipolar Junction Transistor (BJT) is like a water tap, but instead of controlling water, it controls electricity. Just as a tap controls how much water flows, a transistor controls how much electricity flows in devices like radios or computers.

The figures below show the physical transistor and its symbols

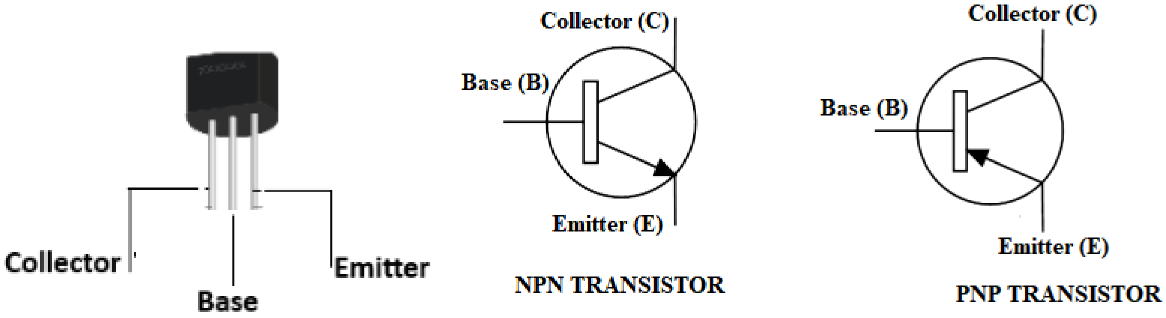


Fig 7.23: Symbol for NPN transistor and PNP transistor

Activity 7.20: Watch and Learn

1. Watch videos on how NPN and PNP transistors work. Here are helpful video links:

a. https://www.youtube.com/watch?v=Sod_5y7ZBlk

b. https://www.youtube.com/watch?v=-VwPSDQmdjM&list=PLwjK_iyK4LLDoFG8FeiKAr3IStRkPSxqq

2. After watching the videos:

a. explain in your own words how an NPN and PNP transistor differ in current flow.

b. Draw the symbols of the two types of transistors and identify the collector, emitter, and base on each diagram.

Reflection Questions:

1. What is the main difference between an NPN and a PNP transistor in terms of current flow?
2. How does doping affect the function of a transistor?
3. Why is the base important in controlling current in a transistor?

Activity 7.21: Build a Simple Transistor Circuit

Objective: Learn how transistors work in a simple circuit.

Materials Needed:

- Battery (9V)
- NPN or PNP transistor
- Resistor (1kΩ)
- LED
- Breadboard and jumper wires

Procedure:

1. Place the transistor on the breadboard.
2. Connect the Collector to the positive terminal of the battery.
3. Connect the Emitter to the LED and then to the negative terminal of the battery.
4. Connect the Base to the positive terminal of the battery through a resistor.

Reflection Questions:

1. What did you observe about the LED's brightness when the Base was connected? How does this observation help you understand the relationship between the Base current and the LED's performance?
2. Based on your observations, what role does the resistor play in the circuit? How does its presence or absence affect the behaviour of the LED and the transistor?

3. From your experiment, how does the transistor in your circuit demonstrate its function as a switch? What specific observations support this behaviour?
4. Considering your circuit setup, how does the transistor's switching action compare to a traditional switch? What insights did you gain about the transistor's role in controlling current flow?
5. What changes do you notice when you swapped the Emitter and Collector connections? How does this affect the circuit's operation, and what does this reveal about transistor configuration?
6. How did the circuit you built show the transistor's dual role as both an amplifier and a switch? What observations led you to understand these functions?

Activity 7.22: Build a Simple Amplifier Using BJT

Materials needed:

- NPN transistor
- Microphone
- Speaker
- 9V battery
- Resistors
- Breadboard and wires

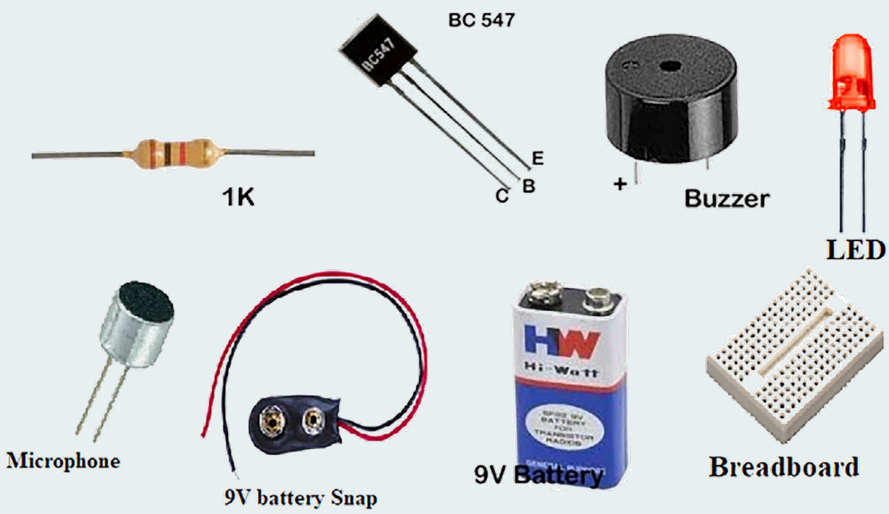


Fig 7.24: Activity materials

Procedure:

1. Connect the microphone to the Base of the transistor using a small resistor.
2. Connect the Collector to the speaker.
3. Power the circuit with a 9V battery.
4. Speak into the microphone.
5. Observe how the sound is amplified through the speaker.

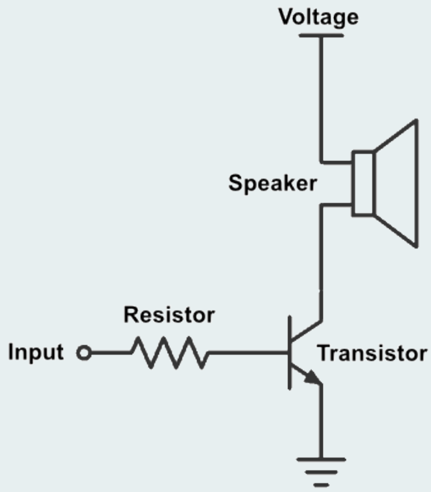


Fig 7.25: schematic of the experimental setup

Discussion:

1. What happened to the speaker or buzzer when you spoke into the microphone? How does this show that the transistor is making the sound louder?
2. How did the small resistor between the microphone and the Base change how the circuit worked? What effect did it have on the sound from the speaker?
3. When you used the 9V battery, how did it affect the speaker's sound? What did you notice about the sound after adding or reducing the supply voltage to the circuit?
4. What did you see when you changed the volume of your voice? How does this show that the transistor changes how much the sound is amplified?
5. From what you observed, how does the transistor make the sound louder? What parts of the sound change show that the transistor is working as an amplifier?

Bipolar transistor biasing

This learning area will guide learners through the concept of transistor biasing, the different biasing techniques, and the role it plays in transistor functioning, particularly for amplification and switching.

Transistor biasing refers to the process of providing the necessary voltage and current to the transistor's terminals (base, collector, and emitter) to set its operating point. Proper biasing ensures that the transistor operates in the desired region, usually the active region for amplification purposes.

Main Types of Biasing

There are four fundamental methods of transistor biasing:

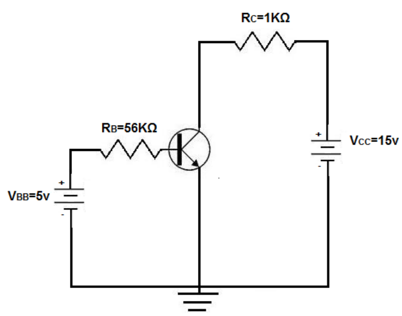
1. Base Biasing
2. Voltage Divider Biasing
3. Emitter Biasing
4. Collector-Feedback Biasing

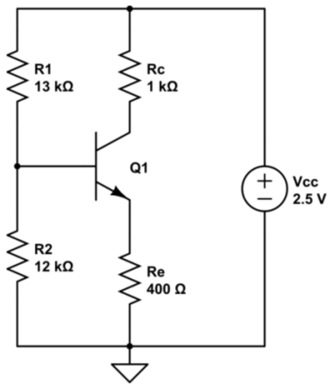
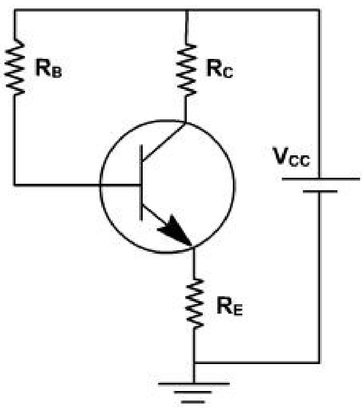
Importance of Biasing

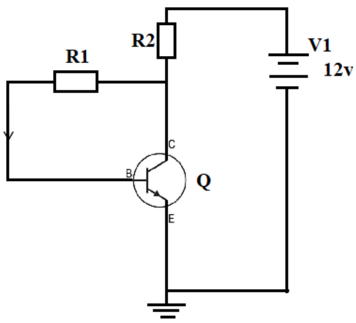
- Biasing ensures the transistor operates efficiently, particularly for amplification and switching.
- It stabilises the transistor's operation, preventing it from entering cut-off (off) or saturation (fully on) regions unintentionally

In this learning area, you will explore these four techniques for preparing a transistor to operate effectively.

Table 7.5: Description, diagram and advantages of the four techniques for preparing a transistor

Type	Description	Diagram	Advantages
Base or fix biasing	This is the simplest type of biasing where a resistor is connected to the Base of the transistor. The resistor limits the current, ensuring that the right amount of power reaches the Base, allowing the transistor to switch on and off.		• Easy to implement: Requires fewer components, making it simple to design. • Useful for basic switching: Suitable for circuits that need basic on/off switching functions.

Type	Description	Diagram	Advantages
Voltage divider bias	This is the most commonly used type of biasing. It uses two resistors connected to the Base to divide the voltage and ensure the transistor gets the right amount of power. An extra resistor called the **Emitter Resistor(R_E)**, helps keep the transistor stable even when conditions change.		• Stability: Provides stable operation even when there are changes in temperature or transistor variations. • Precise control: Ensures accurate voltage levels for proper transistor function. • Widely used: Common in amplifiers because it offers good control of the operating point.
Emitter bias	**Emitter biasing** uses a resistor in the Emitter leg of the transistor. It is very stable and works well when both positive and negative power supplies are available. This type of biasing keeps the transistor working smoothly, even when the temperature or the transistor itself changes.		• High stability: Very dependable in maintaining constant current, even if there are changes in temperature or transistor properties. • Less affected by changes: Provides a steady performance even when the transistor is replaced with another one.

Type	Description	Diagram	Advantages
Collector-feedback biasing	In this type of biasing, a resistor R1 connects the Collector to the Base of the transistor. It helps keep the transistor stable and ensures the transistor works consistently even if the temperature changes.		• Self-stabilising: Automatically adjusts to changes in current or voltage, providing stability. • Simple design: Can be designed with fewer components, saving space and cost. • Temperature compensation: Helps reduce the effect of temperature variations on the transistor's performance.

Real-life examples of Transistor Biasing

- Radios: In radios, biased transistors help make weak sound signals stronger, so we can hear clear sound from the speakers.
- Amplifiers: In music systems or guitar amps, biased transistors make small sound signals louder, allowing us to hear music at a higher volume.
- Computers: Transistors in computers are like tiny switches that control electricity flow. Biasing helps them turn on and off quickly to process information correctly.
- TVs and Smartphones: Transistors help control the screen display and other functions in devices like TVs and smartphones. Biasing ensures they work smoothly.
- Battery Chargers: In battery chargers, transistors are biased to control how electricity flows into the battery, making sure it charges safely and doesn't overheat.

Activity 7.23: Historical Context of Transistor Biasing

Procedure:

Look up information about the history of transistor biasing. Focus on:

1. Key milestones in its development
2. How it has improved electronics and communication technologies
3. Write a short paragraph about:

a. When transistor biasing was first used

b. Why it is important for electronics today

4. Share your findings with the class and discuss how transistor biasing has changed the way we use electronic devices.

Activity 7.24: Real-Life Application and Schematic Design

Procedure:

1. Find Examples: Think of two everyday devices where transistor biasing is necessary. Examples might include:
   a. An amplifier
   b. A radio
2. Draw a simple diagram of a transistor circuit.
3. Show:
   a. How the transistor is biased
   b. The main components of the circuit
4. Write a brief explanation of:
   a. What biasing is
   b. Why it is important for the transistor to work properly in your circuit
5. Present your schematic diagram and explanation to the class.

Activity 7.25: Exploring Biasing with a Simple Circuit

Materials needed:

- 1 NPN transistor
- 1 LED
- Resistors (1 kΩ and 10 kΩ)
- 9V battery
- Breadboard and wires
- Multimeter (optional)

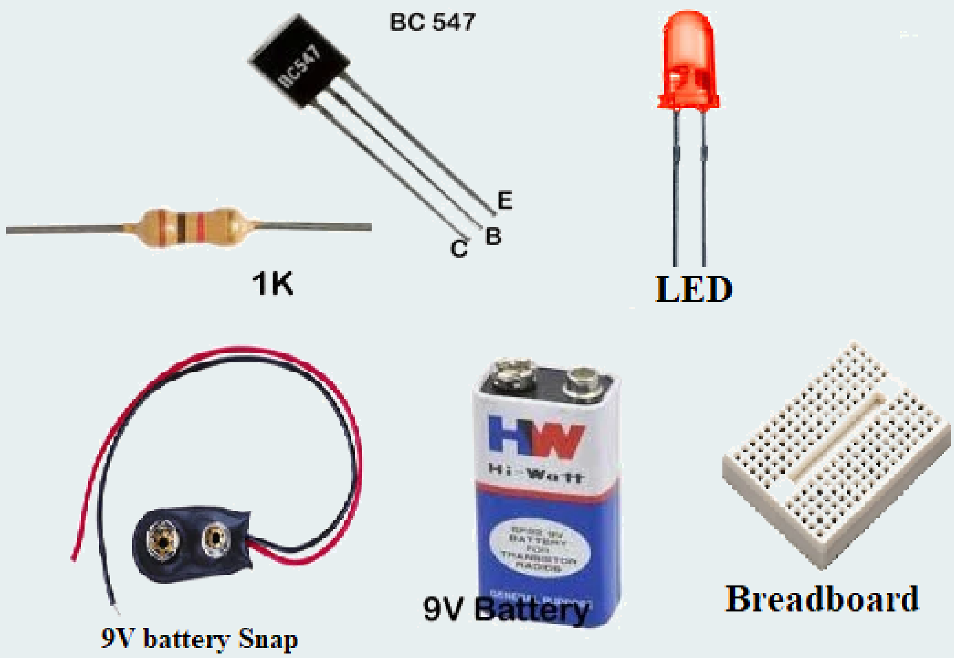


Fig 7.26: Activity materials

Procedure:

Set up the circuit:

1. Insert the NPN transistor into the breadboard.
2. Connect the Emitter to the ground (negative terminal of the battery).
3. Attach the LED between the Collector and the positive terminal of the battery.
4. Connect a 1 kΩ resistor between the Base and the positive terminal.
5. Use the multimeter (if available) to measure the Base voltage.
6. Apply a small current to the Base through the resistor.

7. Observe how the LED lights up when the correct Base voltage is applied.
8. Use different resistors (1 kΩ, 10 kΩ, and 100 kΩ) in the Base leg of the circuit.
9. Observe how the brightness of the LED changes depending on the resistor value (which affects the voltage at the Base).

Discussion:

1. What happens to the LED when you apply voltage to the Base?
2. What do you think will happen if you increase the resistance at the Base?
3. How did the brightness of the LED change when you used different resistors at the Base?
4. What does this tell you about the relationship between Base voltage and the current flowing through the transistor?
5. Discuss your findings with a friend or subject teacher

Various Transistor Configurations

The BJT can be connected in three different ways, known as **configurations**, by keeping one terminal common and using the other two terminals for the input and output. These configurations behave differently to the input signal applied to the circuit due to the **BJT's** basic properties. The three different BJT configurations are listed below.

1. **Common Emitter (CE) Configuration**
    - The common emitter configuration connects the emitter terminal to both the input and output circuits.
    - When a small input signal is applied, it gets amplified to create a larger output signal. This output signal is inverted, meaning it's flipped upside down.
    - Commonly used in amplifiers, like those in radios or speakers.

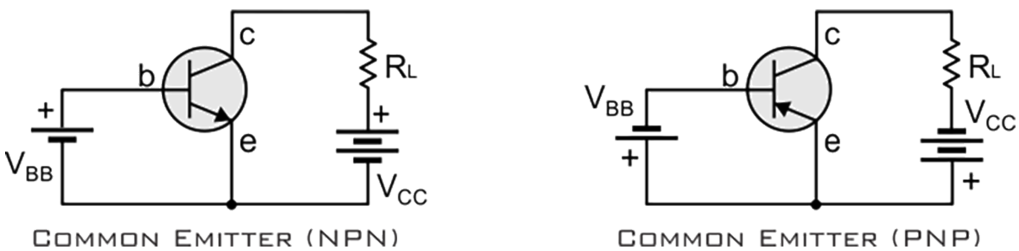


Fig 7.27: Common Emitter Amplifier Configurations (NPN and PNP)

Watch this video by clicking on the link below for a clear explanation
https://www.youtube.com/watch?v=KynKHr2cXgk&list=PLwjK_iyK4LLDoFG8FeiKAr3IStRkPSxqq&index=3

2. Common Collector (CC) Configuration

- In this setup, the collector terminal is connected to both the input and output circuits.
- This configuration provides current amplification, which means it can increase the amount of current without changing the voltage much.
- Often used as a buffer to connect different parts of a circuit without losing signal strength.

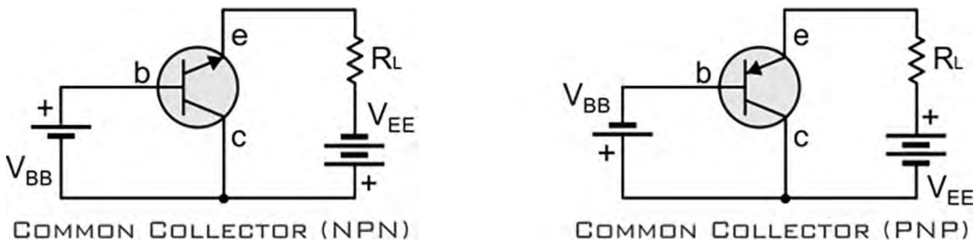


Fig 7.28: Common Collector Amplifier Configurations (NPN and PNP)

Watch the video below by clicking on the link below for a clear explanation
https://www.youtube.com/watch?v=qwWj3bqnuDk&list=PLwjK_iyK4LLDoFG8FeiKAr3IStRkPSxqq&index=4

3. Common Base (CB) Configuration

- Here, the base terminal is common to both the input and output or common to the collector and the emitter
- It has low input resistance and high output resistance, making it effective for high-frequency signals.
- Commonly used in radio frequency applications, such as in communication devices.

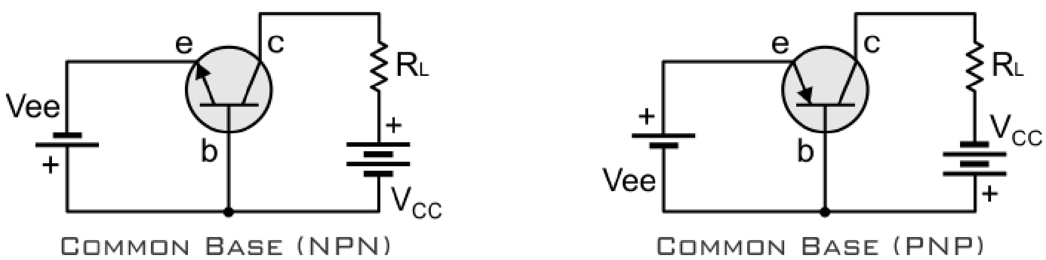


Fig 7.29: Common Base Amplifier Configurations (NPN and PNP)

Watch this video by clicking on the link below for a clear explanation

https://www.youtube.com/watch?v=NMD4KECE-7I&list=PLwjK_iyK4LLDoFG8FeiKAr3IStRkPSxqq&index=2

Table 7.6: Advantages of each of the various transistor configurations

Advantages of Common Emitter (CE) Configuration	Aadvantages of the Common Collector (CC) Configuration	Advantages of common Based (CB) Configuration
1. ***High Voltage increase:*** *Significantly amplifies voltage.*	1. ***High Input Resistance:*** *Uses little power from the input signal.*	1. ***High-Frequency Response:*** *Works well at high frequencies.*
2. ***Moderate Current increase:*** *Provides good current gain.*	2. ***Low Output Resistance:*** *Delivers more power to other parts of the circuit.*	2. ***Low Input Resistance:*** *Efficient for signals with low impedance.*
3. ***Versatile****: Suitable for various applications including amplifiers.*	3. ***Voltage Follower:*** *Keeps the output voltage close to the input voltage.*	3. ***Voltage Gain:*** *Provides significant voltage gain.*
4. ***Signal Amplification:*** *Enhances the strength of signals effectively.*	4. ***Current Gain:*** *Increases the current without changing the voltage*	4. ***Stable Performance:*** *Offers consistent performance in high-frequency applications.*

Activity 7.26: Investigating transistor amplifier configurations

Objective: Build and explore three different transistor configurations: *Common Base*, *Common Emitter*, and *Common Collector.*

NB: *Use the materials provided below for all the activities*

Materials needed:

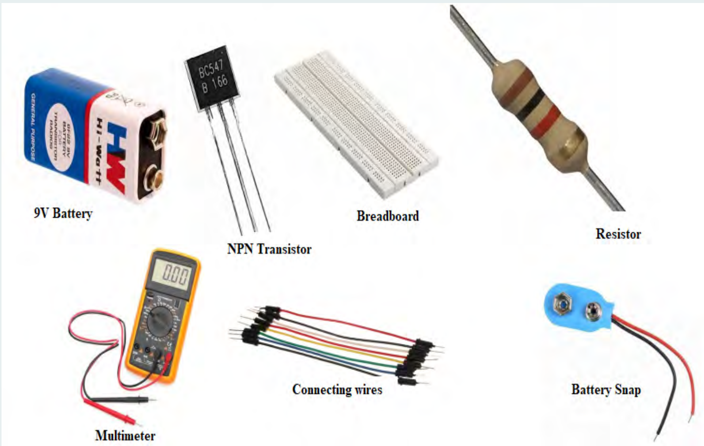


Fig 7.30: Activity materials

Part 1: Common Base (CB) Configuration

Procedure:

1. Place the transistor on the breadboard.
2. Connect the base leg of the transistor to ground.
3. Connect the input signal (positive terminal of the battery) to the emitter.
4. Connect a 2.2k ohm resistor between the collector and the positive terminal of the power supply.
5. Measure the output voltage between the collector and ground using a multimeter.

Reflection questions:

a. *Why is the output signal smaller than the input signal in the Common Base setup? What does this tell you about how the base works in the circuit?*

b. *How does connecting the base to the ground affect the flow of electricity in the circuit?*

c. *Why do we apply the input signal to the emitter and not the collector in this setup?*

d. *What did you notice when you increased the input voltage? How did it change the output?*

e. *Why might this configuration be useful when we want to reduce the strength of a signal?*

Part 2: Common Emitter (CE) Configuration

Procedure:

1. Place the transistor on the breadboard.
2. Connect the emitter to ground through the 1k ohm resistor.
3. Connect the input signal to the base through the 2.2k ohm resistor.
4. Connect the collector to the positive terminal of the power supply.
5. Measure the output voltage between the collector and ground using a multimeter.

Reflection questions:

a. *Why is the output signal stronger than the input signal in the Common Emitter setup? What does this tell you about how the circuit makes the signal bigger?*

b. *What did you notice about the voltage at the collector compared to the emitter? How does this affect the output?*

c. *What happens to the output voltage when you change the input voltage in this setup?*

d. *How does the resistor connected to the emitter change the way the circuit works?*

e. *Why do you think the Common Emitter setup is often used to make signals bigger (amplify them)?*

Part 3: Common Collector (CC) Configuration

Procedure:

1. Place the transistor on the breadboard.
2. Connect the collector directly to the positive terminal of the power supply.
3. Apply the input signal to the base through a wire.
4. Connect the emitter to ground using the 1k ohm resistor.

5. Measure the output voltage between the emitter and ground using a multimeter.

Reflection questions:

a. *Why is the output signal almost the same as the input signal in the Common Collector setup? What does this tell you about the circuit?*

b. *What did you notice about the voltage at the emitter compared to the base? How does this affect the output?*

c. *How does connecting the collector to the positive power source change the circuit?*

d. *What happens to the output signal when you increase the input signal? Why does this happen?*

e. *Why might we use the Common Collector setup to help match signals between different parts of a circuit?*

Annex 7.1 – Solutions to Some Activities (Semiconductors and Diodes)

Activity 7.1

1. N-type semiconductors are doped with pentavalent atoms which increase the number of electrons available to flow in the circuit, thus increasing the conductivity of the semiconductor. P-type semiconductors are doped with trivalent atoms which creates 'holes' in the semiconductor where electrons are missing. The flow of electrons into these holes effectively increases the conductivity of the semiconductor.
2. Phosphorus is pentavalent and so creates an N-type semiconductor when used at the impurity in doping. Boron is trivalent and so creates a P-type semiconductor when used as the impurity in doping.

Activity 7.3

A diode is a device which utilises both N- and P- type semiconductors. The region between the two different semiconductors becomes depleted when they are in contact as the flow of charge in either direction creates charged ions which subsequently become a potential barrier which blocks current flow.

When the diode is then connected to a circuit in forward-bias the depletion region thins, and current is able to flow. In reverse bias, the depletion region widens inhibiting the flow of current.

Activity 7.4

Answers to discussion questions

1. In forward bias, when the battery's positive terminal is connected to the anode and the negative to the cathode, the diode conducts electricity because it allows current to pass through.

2. In reverse bias, when the battery's positive terminal is connected to the cathode and the negative to the anode, the diode blocks current and does not conduct electricity.
3. Diodes allow current to flow in only one direction. This feature is useful for converting AC to DC and protecting circuits by blocking reverse current.
4. A working diode conducts current in forward bias and blocks it in reverse bias. If it doesn't work as expected, it might be damaged.

Annex 7.2 – Further Information on Semiconductor and Diodes

Basic Functions of a Diode:

- **Allows Current to Flow in One Direction**: Diodes let electric current pass in only one direction (forward bias) and block it in the opposite direction (reverse bias).
- **Rectification**: Diodes convert alternating current (AC) to direct current (DC), commonly used in power supplies.
- **Protects Circuits**: Diodes prevent reverse current, protecting sensitive electronic components from damage.
- **Voltage Regulation**: Special types of diodes, like Zener diodes, maintain a constant voltage level.
- **Signal Demodulation**: Diodes are used in radios and communication systems to extract signals from carriers.

Uses of a Diode:

- **Power Conversion**: Diodes are used in power supplies to convert AC to DC (this is known as rectification)
- **Over-voltage Protection**: Diodes protect circuits from voltage spikes.
- **LEDs (Light Emitting Diodes)**: Diodes emit light when current passes through them, used in displays and lighting.
- **Solar Cells**: Diodes are used in photovoltaic cells to convert sunlight into electricity.

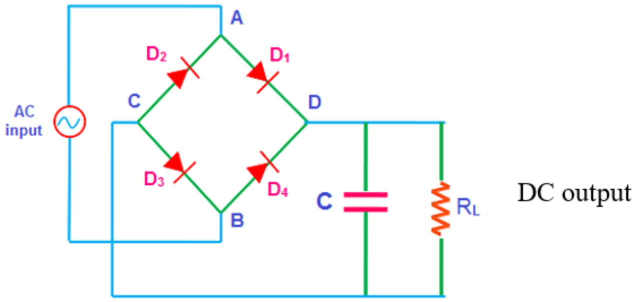


Fig 7.31: Four diodes used in full wave rectification

Types of diodes

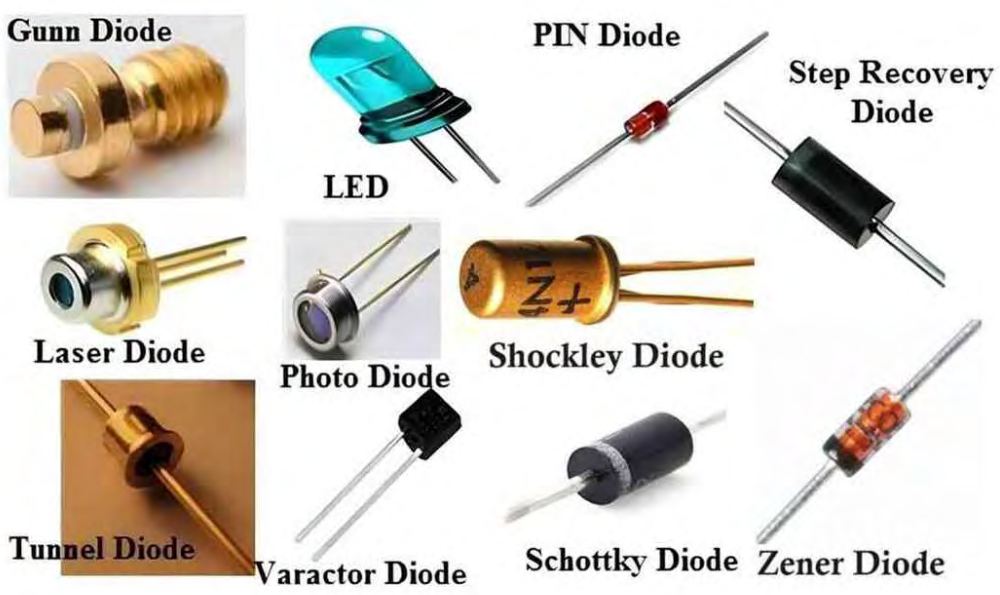


Fig 7.32: Images of various types of diodes

Annex 7.3 – Solutions to Some Activities (LEDs, Zener Diodes, Thermistors and LDRs)

Activity 7.6

Table 7.1: Solution to Activity 7.6

Diodes	Description	Uses
LED	Description: Emits light when current flows through it.	Indicators, displays, backlighting, and general lighting.
Zener diodes	Allows current to flow in reverse direction when a specific voltage (Zener voltage) is reached.	Voltage regulation, over-voltage protection, and reference voltage applications.

Activity 7.8

Automotive Lighting

- Headlights and Taillights
- Indicator Lights

Display Technology

- Televisions and Monitors
- Digital Signage

Decorative Lighting: Architectural Lighting

Medical Applications

- Surgical Lighting
- Therapeutic Devices

Agriculture: Grow Lights: LEDs provide the specific light spectrum needed for plant growth in indoor farming.

Safety and Security

- Exit Signs
- Street and Flood Lighting

Consumer Electronics

- Flashlights and Headlamps
- Indicators and Displays

General Lighting

- Residential Lighting
- Commercial Lighting

Activity 7.10

Applications

- Voltage Regulation: Commonly used in power supplies to provide a stable output voltage.
- Over-voltage Protection: Protect sensitive components by clamping excess voltage.
- Reference Voltage: Serve as voltage references in circuits requiring stability.

Activity 7.11

The temperature-resistance graph for the thermistor shows that the resistance of a thermistor decreases exponentially with temperature (note: this is true for an NTC thermistor only).

The resistance-distance graph for the LDR shows that the resistance of an LDR decreases with distance. The graph may not show an exponential decrease as it is not a resistance-brightness graph.

Activity 7.12

1. Output voltage = current x $\text{resistance}_{\text{thermistor}}$

= (input voltage / total resistance) x $\text{resistance}_{\text{thermistor}}$

At 20 degrees, output voltage = 0.0033 x 500 = 1.67V

At 80 degrees, output voltage = 0.0048 x 50 = 0.23V

2. $100 - 3.5 = 96.5\%$

   $1000 \times (96.5\%)^{25} = 410.4$ Ohms

3. An NTC thermistor. As the temperature increases, the resistance of this type of thermistor decreases. It therefore receives a smaller 'share' of the input voltage, and the fixed resistor receives a larger 'share'. Therefore, the buzzer will sound as if it is in parallel with the fixed resistor.

Annex 7.4 – Further Information on LEDs, Zener diodes, Thermistors and LDRs

Characteristic Curve of Light Emitting Diode

The figure below represents the I-V characteristics of LEDs depending on the colour of light that they emit:

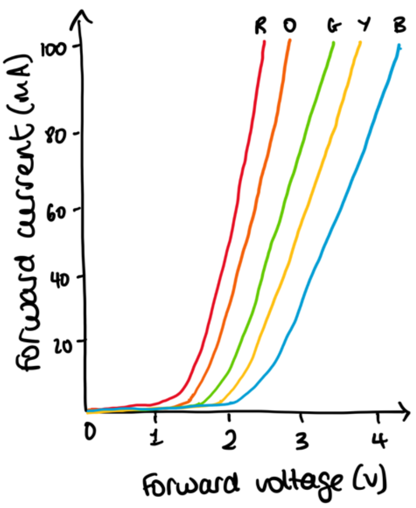


Fig 7.33: I-V Curves for different colour LEDs (R, O, G, Y, B)

Here the x-axis represents the forward applied voltage, and the y-axis shows the forward current flowing through the device.

Zener diodes

Temperature Coefficient

Temperature Sensitivity: The Zener voltage can vary with temperature. Zener diodes come in different temperature coefficients, influencing their stability in varying temperatures.

Power Rating

Maximum Power Dissipation: Zener diodes have a specified maximum power rating, which limits the amount of power they can dissipate without damage.

Reverse Recovery Time

Switching Characteristics: Zener diodes generally have a fast reverse recovery time, making them suitable for high-frequency applications.

To understand the differences between Zener diodes and LEDs (Light Emitting Diodes), you can explore visual explanations through videos and animations.

Here's a link to a useful video on *Khan Academy* explaining Zener diodes and their breakdown process: [Khan Academy Zener Diode Breakdown] (Click here). Additionally, you can visit *Tesca Global* for a practical demonstration using diodes, Zener diodes, and LEDs on a trainer board: [Tesca Global Diodes Overview](Click here).

Annex 7.5 – Solutions to Some Activities (Transducers)

Activity 7.14

Table 7.7: Solution to Activity 7.14

Transducer	Input	Process	Output
Microphone	Sound waves (acoustic energy)	Diaphragm vibrates due to sound waves and converts vibrations into electrical signals.	Electrical signal representing sound
Loudspeaker	Electrical signal (audio)	Electrical signals move the diaphragm via a magnetic field, converting electrical energy to sound.	Sound waves (acoustic energy)
Buzzer	Electrical signal (DC)	Electrical signals create magnetic vibrations in the diaphragm to produce sound.	Audible sound (buzzing)

Transducer	Input	Process	Output
Low Voltage DC Motor	Electrical signal (low-voltage DC)	Electrical current produces a magnetic field that rotates the motor's rotor, converting to mechanical energy.	Mechanical movement (rotation)
Electromagnetic Relay	Electrical signal (control signal)	Energized coil creates a magnetic field that opens or closes a switch to control a larger current.	Electrical switching (on/off control)
Infra-red Diode (IR LED)	Electrical signal (current)	Current causes the diode to emit infrared light through recombination of charge carriers.	Infrared light (radiation)
Piezoelectric sensor	Pressure	A piezoelectric material's charges are shifted when placed under mechanical stress, resulting in an external electric field and the subsequent flow of charge.	Electrical signal
Thermocouple	Heat	When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the thermoelectric circuit. If this circuit is broken at the center, there is a net open circuit voltage (**the Seebeck voltage**) where heat causes charge carriers (electrons or holes) to move from the hot side to the cold side, creating a voltage difference between the two junctions. This is a function of the junction temperature and the composition of the two metals.	Electrical signal

Activity 7.15

Table 7.8: Solution to Activity 7.15

Transducer	Application
Microphone	Telephones, hearing aids.
Loudspeaker	Playing audio files to an audience.
Buzzer	Alarm systems.
Low Voltage DC Motor	Electric fans.
Electromagnetic Relay	Starter motors in cars.
Infra-red Diode (IR LED)	TV remotes.
Piezoelectric sensor	Vibration detection (e.g. seismometer).
Thermocouple	Temperature sensing (e.g. heat alarm, ovens).

Activity 7.16

Loudspeaker

A loudspeaker converts electrical energy into sound. This works by inputting an alternating current into the coil, which is then attracted and repelled from the magnet as the current changes direction. This attraction and repulsion cause the paper cup to vibrate with a frequency within the audio range, and so we hear a sound as the air around the cup vibrates and a longitudinal sound wave is produced.

Activity 7.17

Streetlight

The intensity of the light falling upon the LDR changes its resistance. This, in turns, affects the current in the circuit and the proportion of the support voltage which is given to the LDR and to the fixed resistor. The LED is connected in parallel with the fixed resistor and so receives the same amount of voltage as it. This means that it turns on in dimmer lighting conditions.

Activity 7.18

Buzzer and DC motor

A buzzer and a DC motor both utilise the motor effect to convert energy.

The buzzer contains an electromagnet which becomes magnetised when a current passes through it; this attracts an iron armature and causes a 'ding' when it hits the bell. However, the as the armature is pulled away it disconnects the circuit and so current no longer flows and the armature is no longer attracted; it falls away again. The process repeats.

The DC motor spins because the magnetised wire interacts with the magnetic field it sits in. One side of the coil is forced upwards due to the current direction, but the other side is forced downwards as the current flows the opposite way. The split-ring commutator reverses the current every half turn in order to maintain the same direction of spin.

Activity 7.19

Suggested answers

1. Plan for Transducer System to Monitor White Volta Water Levels

- Transducer Type: Ultrasonic Level Sensor.
- Function: The sensor emits ultrasonic waves, which bounce off the water surface and return to the sensor. The time it takes for the echo to return is used to calculate the water level.
- Benefits:
  - o Real-time monitoring of water levels.
  - o Automatic alerts for rising water, enabling early flood warnings.
  - o Non-contact sensor minimises maintenance and operates reliably in harsh conditions.

N.B. Another option to solve this problem could be a pressure-detecting circuit.

2. Plan for relay circuit

An electromagnetic relay serves as the switch for high-power traffic lights, and a low-voltage control circuit activates the relay, typically from a sensor or control processor. Separate power supplies are used for the low-voltage circuit and high-voltage lights, with transistors or a microcontroller managing the relay's switching based on traffic flow.

When the microcontroller sends a current, the relay's electromagnet is energised, closing the switch and connecting the high-voltage circuit, which powers the red, yellow, or green light. The control system ensures the lights change in sequence. The relay isolates the control circuit from high power, ensuring safe and efficient operation.

Annex 7.6 – Further Information on Transducers

Flow diagrams

A **flow diagram** is constructed by starting with an **oval** shape, which represents the **start** or **end** of a process. From there, we use **arrows** to connect different shapes:

1. **Rectangles** for processes or actions.
2. **Diamonds** for decision points.
3. **Parallelograms** for inputs/outputs.

Each step flows logically from one to the next, guiding through the entire process.

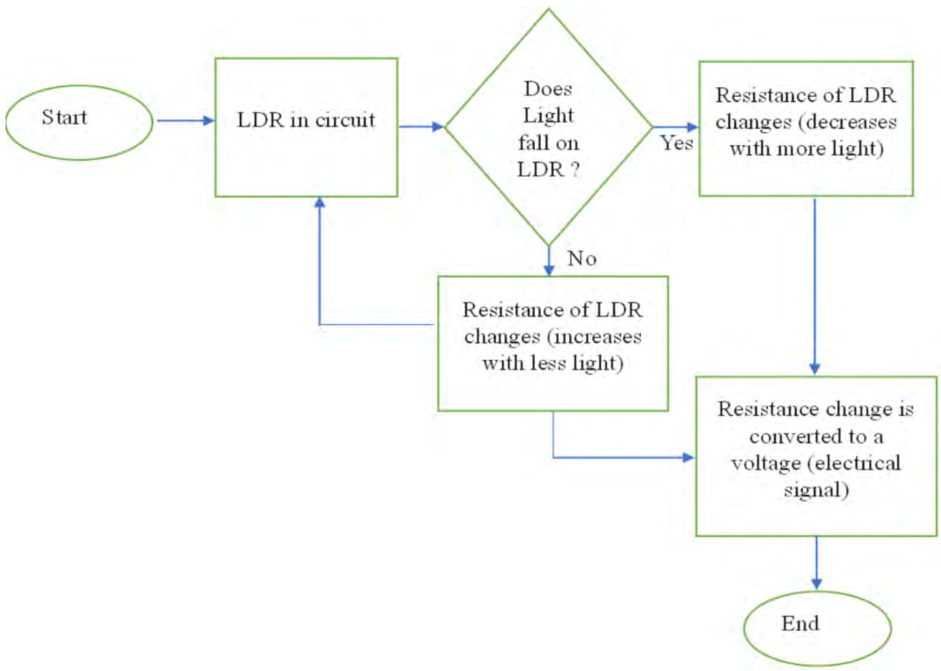


Fig 7.34: Flow diagram, example, of LDR transducer in action

Thermocouples

When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the thermoelectric circuit. If this circuit is broken at the centre, there is a net open circuit voltage (**the Seebeck voltage**) where heat causes charge carriers (electrons or holes) to move from the hot side to the cold side, creating a voltage difference between the two junctions. This is a function of the junction temperature and the composition of the two metals. Thermocouple is used to produce an Analogue Signal.

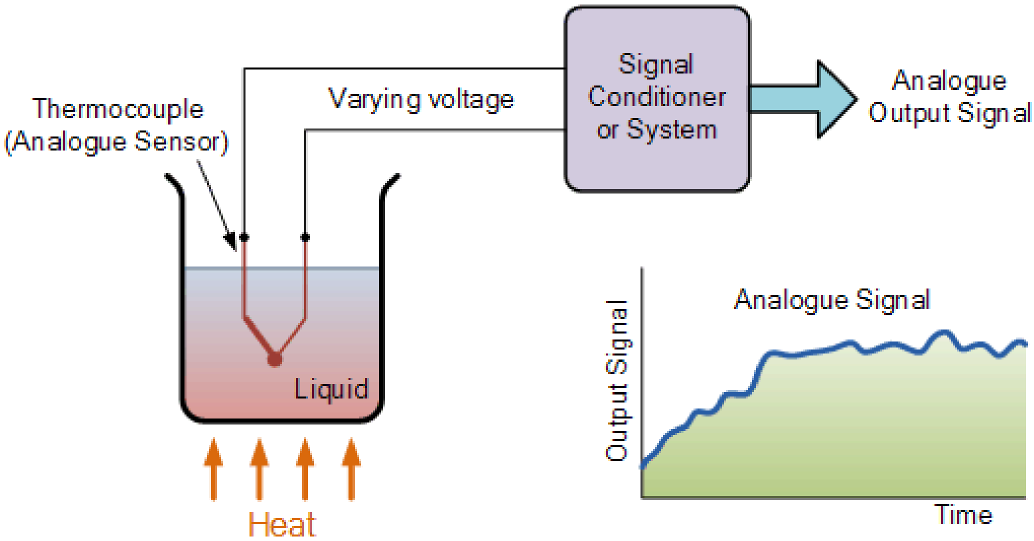


Fig 7.35: Thermocouple Measurement System

Microphones

Microphones work in a way that is just opposite to that of speaker. A magnetic field is produced by a permanent magnet which is inserted into an electrical conductor coil (generally copper). When we speak, it creates vibration on a diaphragm which in turn vibrates the coil and induces a current within it. The alternating electrical signal can be supplied to a speaker to convert back into sound.

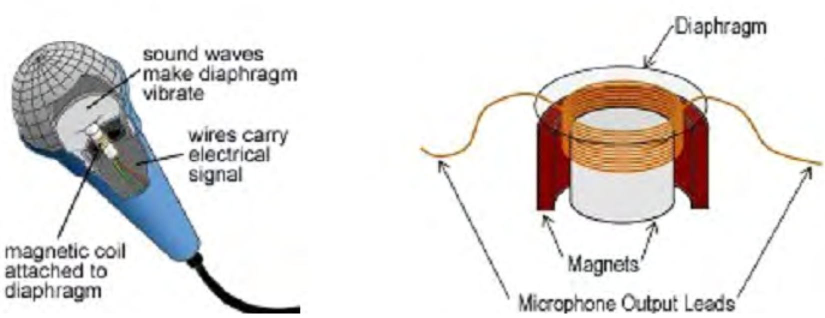


Fig 7.36: Microphone and its internal functional mechanism

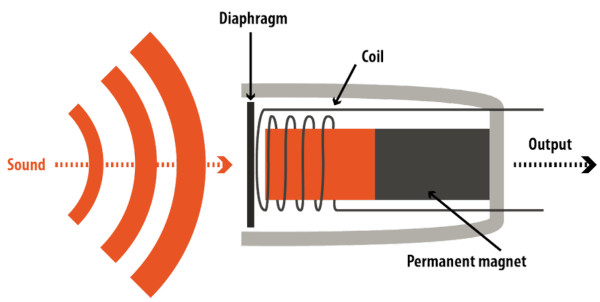


Fig 7.37: Microphone internal mechanism showing sound vibration on a diaphragm

Electromechanical Relay

It is sometimes necessary to design circuits which allow the (human) user to interact with a low-voltage electrical signal but to subsequently 'turn on' a high-voltage circuit. This is a safety precaution which reduces the risk of, for example, fatal electric shocks.

The user presses a switch connected to a low-voltage circuit containing a coil of wire (solenoid). When current flows through this relay coil the soft iron core behaves as a strong magnet causing the opened contact to close, hence causing high current or voltage to flow and, for example, light a 230 V lamp.

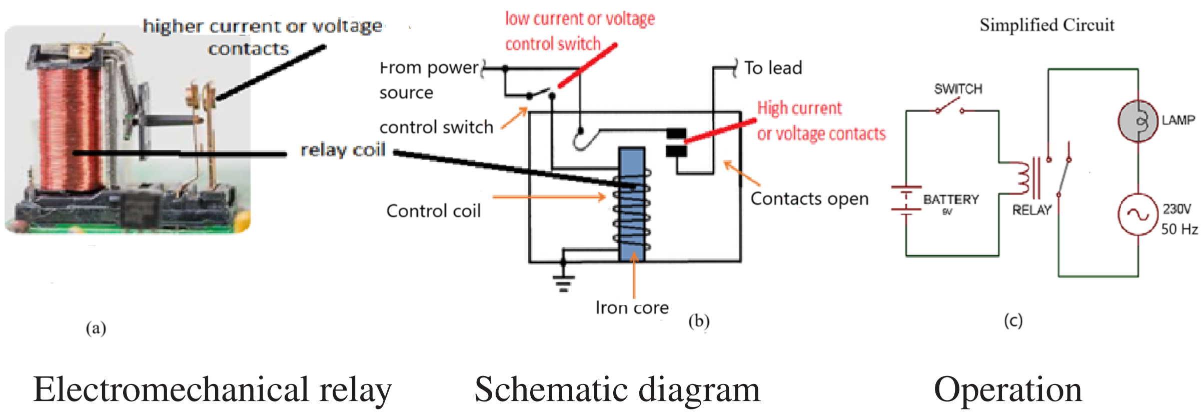


Fig 7.38: Electromechanical relay in simplified circuit

Infrared diodes

The infrared diode converts electrical signals into infrared light, much like a visible light LED, which transmits coded signals to the device being controlled (e.g., TV).

REVIEW QUESTIONS

Review Question 7.1

1. How does the arrangement of p-type and n-type materials in a p-n junction diode affect its ability to conduct electricity in different directions?
2. Explain why a p-n junction diode conducts electricity in forward bias but not in reverse bias. How does this impact its use in electronic circuits?
3. Analyse how diodes are used in rectifiers to convert alternating current (AC) to direct current (DC). Why is the diode's ability to block current in reverse bias crucial for this process?
4. Investigate how the process of doping is used to create the p-type and n-type materials in a p-n junction diode. How do these materials influence the behaviour of the diode under different voltage conditions?
5. Analyse how the difference in charge carriers between n-type and p-type semiconductors impacts their behaviour in an electric field.
6. Describe the process of doping a pure semiconductor. How does the choice of impurity affect whether the material becomes n-type or p-type?

Review Question 7.2

1. What are the benefits of LEDs?
2. What is the I-V characteristic of a Zener diode?
3. How does temperature affect the resistance of a thermistor?
4. What is the characteristic graph of an LDR?
5. How does an infrared diode respond to temperature changes?
6. What is the application of a Zener diode in a power supply circuit?
7. What is the difference between a thermistor and an LDR?

Review Question 7.3

1. Explain the difference between the input and output of a transducer. Give two examples of transducers and describe their input and output.
2. Describe how a microphone and a loudspeaker work. What type of energy conversion happens in each?
3. Identify and categorise the following transducers based on their input and output energies: buzzer, infrared diode, and DC motor.
4. Describe how the sound reaching a microphone is converted into an electrical signal.
5. Describe the energy conversion that takes place in a DC motor and give one example of its application.
6. How does an infrared diode work in a remote control system?
7. Compare the operation of an electromagnetic relay and a DC motor. How are they similar and different in terms of function?
8. Evaluate the importance of transducers in modern technology and provide examples from at least three different fields.
9. Design an experiment to demonstrate the function of an electromagnetic relay in controlling a simple circuit with a light bulb and a switch.

Project Work

Research on a different type of transistor and produce a short presentation or poster explaining their function and examples of where they are used.

Review Question 7.4

1. What are the three main parts of a Bipolar Junction Transistor (BJT), and what is the main function of each part?
2. How does the size of the Collector compare to the Emitter, and why is this the case?
3. Describe a simple experiment you could perform to observe the role of each part of the transistor.
4. What is the purpose of biasing a transistor in a circuit?
5. Explain how a Voltage Divider Biasing method works.

6. What happens to the transistor's performance if the biasing is not set correctly?
7. How does Emitter Biasing improve the stability of a transistor circuit?
8. What is the main difference between the common emitter, common base, and common collector transistor configurations?
9. How does the input and output signal relationship differ in a common emitter configuration compared to a common collector configuration?
10. In a common base transistor configuration, how does the voltage gain compare to the current gain, and why?
11. Explain why the common emitter configuration is often used for amplification purposes.
12. Describe the role of the base in a common emitter transistor configuration and how it affects the transistor's operation.
13. How does the biasing of a transistor differ between the common emitter and common collector configurations?
14. What are the advantages of using a common collector configuration in a circuit design?
15. How does the frequency response of a common base configuration compare to that of a common emitter configuration?
16. Analyse a circuit with a common emitter transistor configuration. If the input signal is applied to the base, where is the output taken, and what is the phase relationship between the input and output signals?
17. Describe how the choice of transistor configuration can impact the overall performance of an amplifier circuit.

Project Work

Design a basic transistor amplifier circuit using the common emitter configuration. Draw the circuit diagram, specify the component values, and explain how the circuit amplifies the input signal.

ANSWERS TO REVIEW QUESTIONS

Answers to Review Question 7.1

1. The p-type side has positive charges (holes), and the n-type side has negative charges (electrons). In forward bias, they move toward each other, allowing current to flow. In reverse bias, they move apart, stopping the current.
2. In forward bias, the voltage lowers the barrier, so current flows. In reverse bias, the voltage increases the barrier, blocking current. This makes diodes useful for letting current flow in one direction in circuits like rectifiers.
3. Diodes in rectifiers allow current to flow during the positive part of an AC cycle and block it during the negative part. This turns AC into DC, which is needed for most electronic devices.
4. Doping adds impurities to create p-type (with holes) and n-type (with extra electrons) materials. When combined, they form a p-n junction, and their behaviour depends on how voltage is applied (forward or reverse bias).
5. In n-type semiconductors, extra electrons move towards the positive side. In p-type semiconductors, holes (missing electrons) move towards the negative side.
6. Doping adds special atoms to a semiconductor. If these atoms have extra electrons, it makes n-type material. If they create holes, it makes p-type material.

Answers to Review Question 7.2

1. Benefits of LEDs:
   - Energy efficiency
   - Long lifespan
   - Environmentally friendly
   - High brightness and intensity
   - Design flexibility

2. I-V characteristic of a Zener diode:
   - Reverse breakdown voltage
   - Constant voltage output in reverse bias
3. Effect of temperature on thermistor resistance: Decreases with increasing temperature (NTC)
4. Characteristic graph of an LDR: Resistance decreases with increasing light intensity
5. Response of infra-red diode to temperature changes: Voltage output increases with increasing temperature
6. Application of Zener diode in a power supply circuit: Voltage regulation and surge protection
7. Thermistor vs LDR: Thermistor responds to temperature changes, while LDR responds to light intensity changes

Answers to Review Question 7.3

1. Input: The physical quantity (e.g., sound, light) sensed by the transducer.
   - Output: The electrical signal produced.
   - Examples:

     Microphone: Input = sound waves, Output = electrical signal.

     Loudspeaker: Input = electrical signal, Output = sound waves.
2. Microphone: Converts sound energy into electrical energy.

   Loudspeaker: Converts electrical energy into sound energy.
3. Buzzer: Input = electrical energy, Output = sound energy.
   - Infrared diode: Input = electrical energy, Output = infrared light energy.
   - DC motor: Input = electrical energy, Output = mechanical (rotational) energy.
4. A microphone is connected to a power source and an amplifier. When sound waves hit the microphone diaphragm, it vibrates and produces a corresponding electrical signal, which is then amplified to be detected or recorded.
5. A DC motor converts electrical energy into mechanical (rotational) energy. One example is its use in toy cars to power the wheels.

6. The infrared diode converts electrical signals into infrared light, which transmits coded signals to the device being controlled (e.g., TV).
7. **Similarities**: Both convert electrical energy into mechanical action.

   Differences: The DC motor produces continuous rotation, while the relay uses electrical energy to open/close a switch for controlling other circuits.
8. Transducers are vital for converting physical phenomena into usable electrical signals. Examples:
   - Medical: Ultrasound transducers for imaging.
   - Automotive: Temperature sensors in engine management.
   - Communication: Microphones in smartphones.
9. Use a low-voltage DC supply to energise the relay coil. When the relay is activated, the switch closes, allowing a higher voltage circuit to power a light bulb. This shows how a small current can control a larger one.

Answers to Review Question 7.4

1. The three main parts of a BJT are the Emitter, Base, and Collector. The Emitter emits charge carriers, the Base controls the flow of these carriers, and the Collector collects the carriers from the Emitter.
2. The Collector is usually larger than the Emitter because it needs to handle a higher amount of current and dissipate more heat.
3. Connect a transistor in a basic circuit with an LED. Observe how the LED lights up when a small current is applied to the Base, showing how the Emitter and Collector work together to allow a larger current to flow.
4. The purpose of biasing is to set the transistor to operate in the correct region (active, cutoff, or saturation) to perform its function properly, such as amplifying signals or switching.
5. Voltage Divider Biasing uses two resistors to set a stable voltage at the Base of the transistor, ensuring consistent operation despite changes in other parts of the circuit.
6. Incorrect biasing can cause the transistor to operate inefficiently or not at all, leading to poor performance or malfunction of the circuit.
7. Emitter Biasing provides a stable operating point by applying a voltage to both the Base and Emitter, which helps to maintain consistent performance despite variations in temperature or power supply.

8. Common emitter: high gain and signal inversion. Common base: high frequency response but low gain. Common collector: high current gain and no signal inversion.

9. Common emitter: output is inverted and amplified. Common collector: output follows input with no inversion.

10. Voltage gain is higher than current gain due to better high-frequency response.

11. It provides high voltage and current gain, making it effective for boosting signals.

12. The base controls current flow from collector to emitter. A small base current results in a large collector current.

13. Common emitter: base-emitter junction is forward-biased. Common collector: biasing ensures stable output voltage.

14. Provides high current gain and acts as a voltage follower.

15. Common base has better high-frequency response.

16. Output is taken from the collector, and the signal is inverted.

17. Common emitter: high gain and inversion. Common collector: stable output voltage and high current gain. Common base: high-frequency performance.

EXTENDED READING

Use the following books and videos to learn more about topics discussed in this section

- https://byjus.com/physics/p-n-junction/
- https://www.youtube.com/watch?v=OsfguONJw2Q
- https://www.youtube.com/watch?v=s6rQI7t9XM4
- Getting Started in Electronics,1988, Forrest M. Mims, III. Contributing Editor, Modern Electronics, Printed in USA. Pg 127
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- https://www.tutorialspoint.com/amplifiers/methods_of_transistor_biasing.htm
- https://byjus.com/physics/bipolar-junction-transistor/
- https://sites.pitt.edu/~qiw4/Academic/ME2082/Transistor%20Basics.pdf
- https://www.vedantu.com/physics/common-emitter-configuration
- https://byjus.com/jee/transistor-as-a-switch/
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7. “Microelectronic Circuits” by Adel S. Sedra and Kenneth C. Smith
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9. Khan Academy - Semiconductors and PN Junctions
10. Coursera - Semiconductor Devices
11. edX - Microelectronic Devices
12. Electronics Tutorials - LEDs, Zener Diodes, Thermistors, LDRs
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14. “Zener Diodes: Principles and Applications” by A. K. Singh et al. (IEEE Transactions on Electron Devices)
15. “Thermistors: Temperature Sensing and Control” by R. N. Singh et al. (Sensors and Actuators A: Physical)
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20. https://www.quora.com/What-is-a-simple-circuit-with-a-relay

21. https://islproducts.com/design-note/piezo-buzzers-vs-magnetic-buzzers/

22. Plastic cup microphones: https://youtu.be/QFffKMH73EU

23. Flowchart Tutorial (with Symbols, Guide and Examples) https://www.visual-paradigm.com/tutorials/flowchart-tutorial/

24. How to make a speaker: https://youtu.be/MA1n16iyaeg

25. Making a Paper Cup Microphone. Less than $10!: https://youtu.be/1hU6wrR2J24

26. DIY Ribbon mic How to Make a microphone RCA Inspired https://youtu.be/HOuL5glv8pA

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ACKNOWLEDGEMENTS

Ghana Education Service (GES)

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