CHAPTER 5

Electronics

What are thermionic emission and cathode rays?

What are the function and uses of a semiconductor diode?

What are the functions of a npn transistor or pnp transistor?

How does a transistor function in an amplifier circuit?

How does a transistor function as an automatic light-controlled switch and heat-controlled switch?

You will learn:

Learning Standards and List of Formulae in Chapter 5

Information Portal

The invention of the semiconductor diode and transistor in the 20th century has led to the Digital Revolution. This period has transformed life as we know it due to the technological development from mechanical and analog to digital. Diodes and transistors in the form of electronic microchips, which are central of all of our electronic devices are easily available and have many benefits. The light emitting diode or LED is used as the source of light. LED is also used as indicator lamp in industrial machines.

In addition, Artificial Intelligence (AI) is increasingly dominating our lives. Many of the devices today can function automatically, such as robots and self-driving cars. Most of the electronic chips today are designed to be increasingly smaller. Smaller chips not only save space and electrical power but also improve the overall efficiency of the system.

https://bit.ly/31M6J7Q

Importance of the Chapter

In the era of the Fourth Industrial Revolution (IR 4.0), understanding the nature of electrons, applications of diodes and transistors, artificial intelligence (AI) and 5G internet enables electronic engineers and algorithm experts to create smart electronic devices and automation systems. Such progress can improve the industry's productivity and national revenue.

Futuristic Lens

Artificial intelligence (AI) enables in-depth studies on robots and self-driving cars. Research into this field also contributes to the development of smart cities which are more nature-friendly to maintain a sustainable lifestyle.

https://bit.ly/2QItiEc

5.1 Electron

Thermionic Emission and Cathode Rays

You have learnt that current, I is the rate of flow of charges in a conductor. An electric current is produced when charged particles (electrons) flow in a conductor. Can electrons move through a vacuum without a conductor?

Activity 5.1

ISS ICS

Aim: To generate idea on thermionic emission and cathode rays

Instructions:

1. Carry out this activity in groups.
2. Scan the QR code to watch the video on thermionic emission and cathode rays.
3. Based on the video, discuss the following:
   (a) What is thermionic emission?
   (b) What are the functions of the 6 V power supply and the extra high tension (E.H.T) power supply?
   (c) Why must the tube be in a state of vacuum?
   (d) How can cathode rays be produced in a vacuum tube?
4. Present your findings.

SCAN ME
EduwebTV: Thermionic emission and cathode rays
https://bit.ly/3gJuQII

Figure 5.1 explains the thermionic emission and the production of cathode rays in a vacuum tube using extra high tension (E.H.T.) power supply.

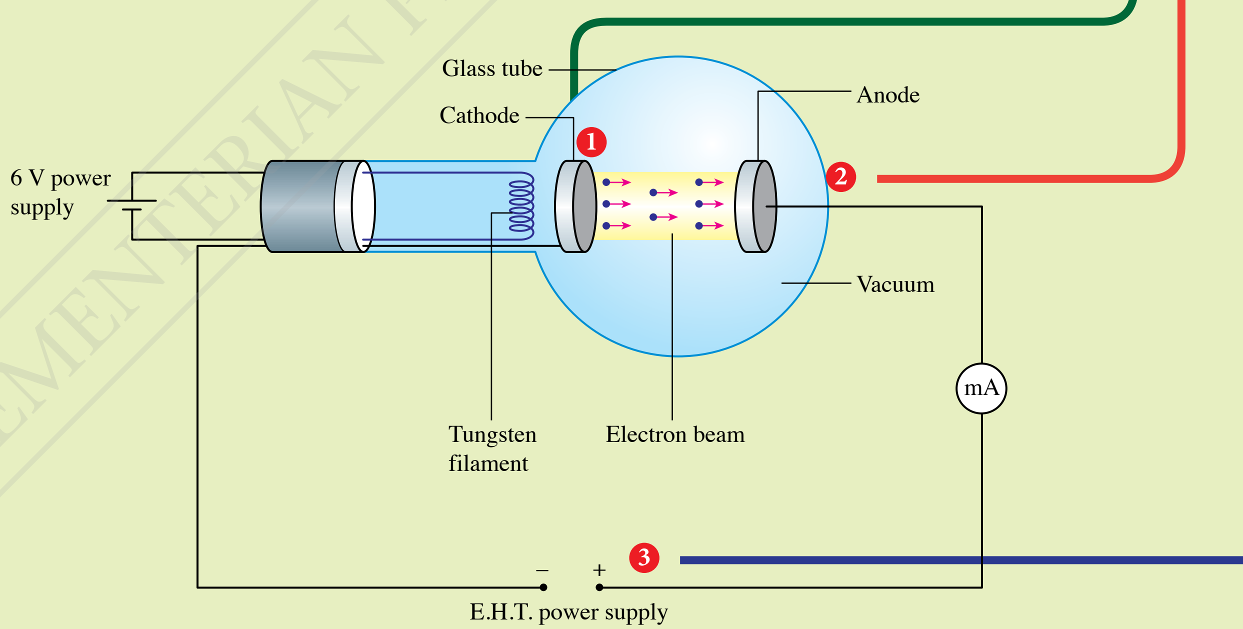
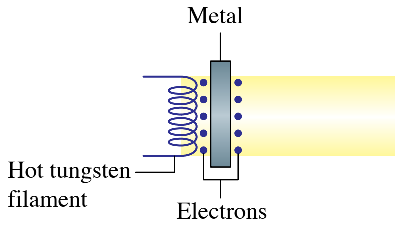


***Figure 5.1** Thermionic emission and production of cathode rays in a vacuum tube*

LS 5.1.1

1

There are many free electrons in a metal wire, for example, tungsten filament. When the 6 V d.c. power supply is switched on, the temperature of the tungsten filament will rise and the free electrons will gain sufficient kinetic energy to leave the metal surface. **Thermionic emission** is **the emission of free electrons from a heated metal surface.**



Info GALLERY

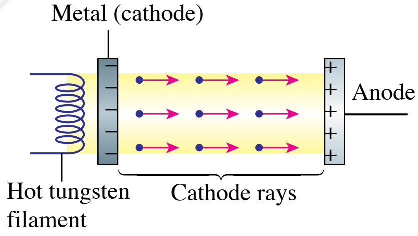
If a layer of metal oxide like barium oxide or strontium oxide is coated on the metal surface cathode in the vacuum tube, the temperature required to release the electrons will be reduced.

2

In a glass vacuum tube, the electrons are able to accelerate towards the anode without colliding with air molecules. Hence, there is no energy loss and electrons move with the maximum velocity.

3

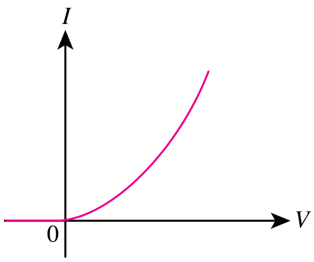
- When a vacuum tube is connected to an E.H.T. power supply, the electrons emitted from the cathode will be attracted to the anode at high velocity to form an electron beam. This **high velocity electron beam** is known as **cathode rays**. The electron beam will complete the E.H.T. power supply circuit and the milliammeter reading will show that a current is flowing.



- If the connection to the E.H.T. power supply is reversed, the milliammeter will not show any reading.

Info GALLERY

The graph below shows a graph of current against voltage for a thermionic diode. This shows that a thermionic diode is a non-ohmic component.



Graph of I against V

Effects of Electric Field and Magnetic Field on Cathode Rays

Cathode rays are **beams of electrons moving at high speed in a vacuum**. The characteristics of cathode rays can be studied using a deflection tube and a Maltese cross tube. Carry out Activity 5.2 and Activity 5.3 to study the effects of electric field and magnetic field on the direction of cathode rays.

Activity 5.2 Teacher's demonstration

Aim: To study the effects of an electric field on cathode rays using a deflection tube

Apparatus: Deflection tube, 6 V power supply, E.H.T. power supply and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 5.2.

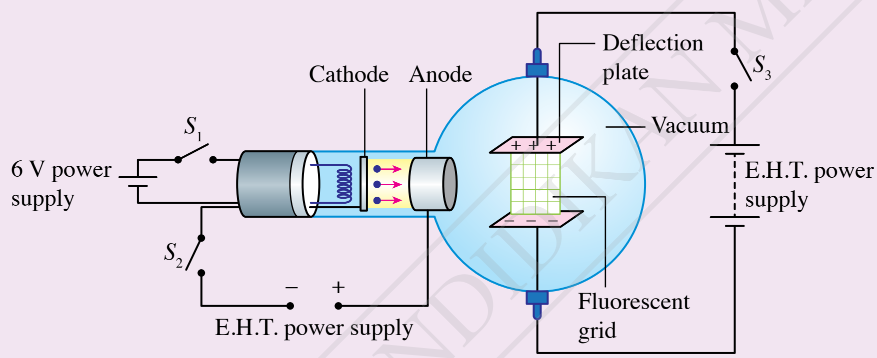


***Figure 5.2** Deflection tube*

2. Turn on switch S_1 for the 6 V power supply and switch S_2 for the E.H.T. power supply. Record your observations.
3. Turn on switch S_3 at the E.H.T. power supply that is connected to the deflection plates. Observe the cathode rays deflection on the fluorescent grid.
4. Reverse the connection at the E.H.T. power supply that is, connected to the deflection plates and repeat step 3.
5. Record all your observations.

SCAN ME
Demonstration video of a deflection tube
https://bit.ly/2Z92QZ9

Discussion:

State your observations on the fluorescent grid when:

(a) switches S_1 and S_2 are turned on
(b) switches S_1, S_2 and S_3 are turned on
(c) switches S_1, S_2 and S_3 are turned on and the potential difference at the deflection plates is reversed

Safety Precaution

- Do not touch any metal part of the deflection tube while using the E.H.T. power supply.
- Ensure that the E.H.T. power supply is switched off when no observations are made.

Activity 5.3 Teacher's demonstration

Aim: To study the effects of a magnetic field on cathode rays using a Maltese cross tube

Apparatus: Maltese cross tube, 6 V power supply, E.H.T. power supply, bar magnet and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 5.3.

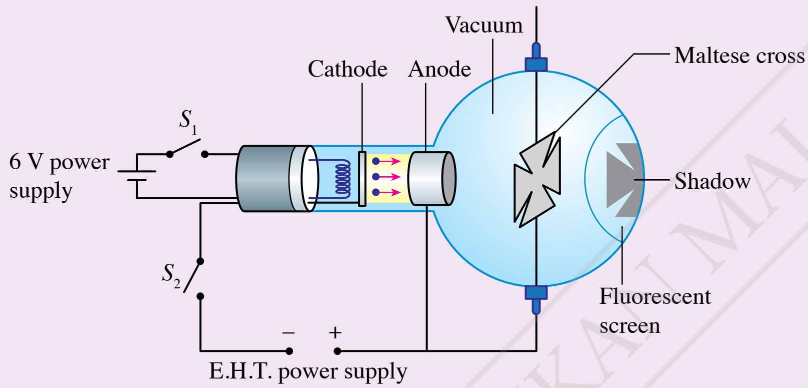


Figure 5.3 *Maltese cross tube*

2. Turn on switch S_1 of the 6 V power supply. Observe the shadows formed on the fluorescent screen. Record your observation.
3. Turn on switch S_2 and observe the shadow formed on the fluorescent screen again.
4. Bring the north pole of a magnet to the right side of the Maltese cross tube and observe changes of the shadow.
5. Record all your observations.

Discussion:

1. State your observations of the shadow formed on the fluorescent screen when:
   (a) switch S_1 is turned on
   (b) switches S_1 and S_2 are turned on
   (c) switches S_1 and S_2 are turned on and the north pole of a magnet is brought to the side of the Maltese cross tube.
2. Explain your observations when the north pole of a magnet is brought to the right side of the Maltese cross tube.

SCAN ME
Demonstration video of a Maltese cross tube
https://bit.ly/3bf1SPR

Safety Precaution

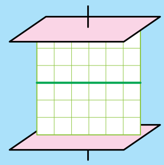
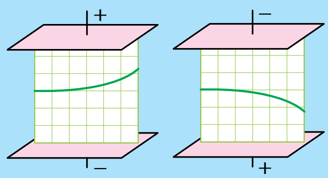
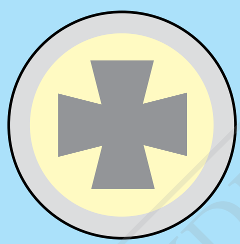
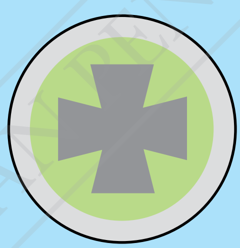
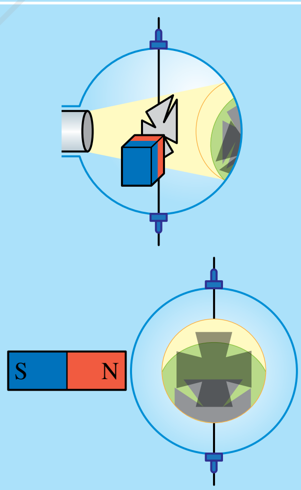
- Do not touch any metal part of the Maltese cross tube while using the E.H.T. power supply.
- Ensure that the E.H.T. power supply is switched off when no observations are being recorded.

Note

Ensure that the Maltese cross tube is properly earthed when the experiment is running.

Table 5.1 summarises the effects on electric field and a magnetic field on cathode rays.

***Table 5.1** Observations and explanations on the characteristics of cathode rays*

Apparatus	Condition of switch	Observations	Explanation
Deflection tube	S_1 and S_2 are turned on		• Cathode rays travel in a straight line.
	S_1, S_2 and S_3 are turned on		• Cathode rays **can be deflected by an electric field**. They are deflected towards the positive plate in a parabolic path. • Cathode rays are **negatively charged**.
Maltese cross tube	S_1 is turned on		• Light from the hot tungsten filament is be blocked by an opaque object (Maltese cross) to form a shadow. Light travels in a straight line.
	S_1 and S_2 are turned on		• Cathode rays are **blocked** by Maltese cross to form a shadow. Cathode rays **travel in a straight line**. • Cathode rays also **produce a fluorescent effect** on the screen surrounding the shadow. This shows that cathode rays **possess momentum and kinetic energy**.
	S_1 and S_2 are turned on and magnet is placed near the tube		• One shadow is due to the light from the hot tungsten filament. • The other shadow is due to the deflection of the cathode ray by the bar magnet that is placed near the tube. • The deflection of cathode rays can be determined by Fleming's left-hand rule.

Velocity of an Electron in a Cathode Ray Tube

Figure 5.4 shows the formation of cathode rays in a vacuum tube. The electrical potential energy, E of an electron is given by:

$$E = eV$$

where E = electrical potential energy
e = charge of an electron
V = potential difference between the cathode and the anode of the E.H.T. power supply

The charge of an electron is 1.6×10^{-19} C

SCAN ME
Demonstration video of a cathode ray tube
https://bit.ly/34TKCye

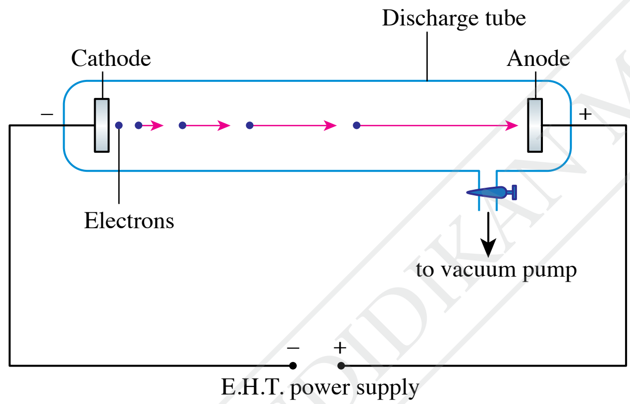


Figure 5.4 *Cathode ray tube*

When the E.H.T. power supply is turned on, electrons are attracted by the positively charged anodes. As there are no air molecules in the vacuum tube, electrons will accelerate to the anode without any collision. These electrons will achieve maximum velocity, v_{max} when they reach the anode.

Applying the principle of conservation of energy,

The electrical potential energy = the maximum kinetic energy

$$eV = \frac{1}{2}mv^2_{max}$$

where e = charge of an electron
V = potential difference between cathode and anode
m = mass of an electron
v_{max} = maximum velocity of an electron

The charge of an electron is 1.6×10^{-19} C and the mass of an electron is 9.11×10^{-31} kg

Brain-Teaser

Before the invention of plasma and LCD televisions, the old versions of televisions were bulky because they used a cathode ray tube. What innovation has led to the invention of plasma and LCD television?

Example 1

Figure 5.5 shows an electron beam that is accelerated from the cathode to the anode in a vacuum. The potential difference across the cathode and the anode is 550 V.
[Mass of an electron, $m = 9.11 \times 10^{-31}$ kg, charge of an electron, $e = 1.6 \times 10^{-19}$ C]
(a) What is the electrical potential energy of an electron?
(b) What is the kinetic energy of an electron when it reaches at the anode?
(c) What is the maximum velocity of an electron when it reaches at the anode?

LET'S ANSWER
https://bit.ly/3bgsC25

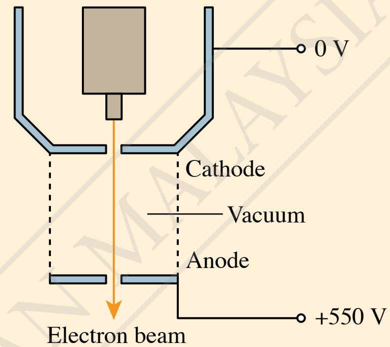


Figure 5.5

Solution

Potential difference across cathode and anode, $V = 550$ V
Charge of an electron, $e = 1.6 \times 10^{-19}$ C
Mass of an electron, $m = 9.11 \times 10^{-31}$ kg

(a) Electrical potential energy of an electron $= eV$
$= 1.6 \times 10^{-19} \times 550$
$= 8.8 \times 10^{-17}$ J

(b) Applying the principle of conservation of energy:
Kinetic energy gained by an electron
= Electrical potential energy of an electron
$= 8.8 \times 10^{-17}$ J

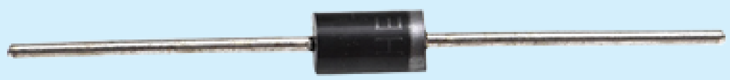
(c)
$$\frac{1}{2}mv_{max}^2 = eV$$
$$v_{max} = \sqrt{\frac{2eV}{m}}$$
$$= \sqrt{\frac{2 \times 8.8 \times 10^{-17}}{9.1 \times 10^{-31}}}$$
$$= 1.39 \times 10^{7} \text{ m s}^{-1}$$

Formative Practice 5.1

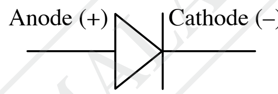
1. (a) What are thermionic emission and cathode rays?
   (b) State the characteristics of cathode rays.
2. (a) State the function of the components of a cathode ray tube below:
   (i) heating filament
   (ii) cathode
   (iii) anode
   (iv) fluorescent screen
   (b) Why must a cathode ray tube be in a state of vacuum?
3. When an electron beam moves from the cathode to the anode in a vacuum tube, state:
   (a) the type of motion of the electron beam
   (b) the transformation of energy
   (c) the relationship between the voltage of E.H.T. power supply and the velocity of the electron
4. When an E.H.T. with power of 800 V is connected across the cathode and the anode, what is the velocity of the electron? What is the effect on the velocity of the electron if the voltage is increased by four times?
   [Charge of an electron, $e = 1.6 \times 10^{-19}$ C, mass of an electron, $m = 9.11 \times 10^{-31}$ kg]

5.2 Semiconductor Diode

You have learnt that the transmission of electrical power to consumers through a network is in the form of alternating current (A.C.). However, in everyday life, many electrical devices can only function with direct current (D.C.). Therefore, the alternating current has to be converted into a direct current. Photograph 5.1 shows a semiconductor diode which functions to convert alternating current into direct current.



Photograph 5.1 Semiconductor diode



Diode symbol

Activity 5.4

Aim: Discuss the function of a semiconductor diode

Apparatus: Diode, dry cell, cell holder, bulb and connecting wires

Instructions:

1. Connect the diode in forward biased as shown in Figure 5.6, that is, the positive terminal of the dry cell is connected to the anode and the negative terminal to the cathode.
2. Observe the bulb and record your observation.
3. Reverse the connection of the dry cell so that the diode is in reverse biased as shown in Figure 5.7, that is, the positive terminal of the dry cell is connected to the cathode and the negative terminal to the anode.
4. Observe the bulb and record your observation.

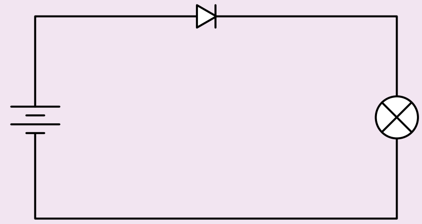


Figure 5.6 *Circuit A*

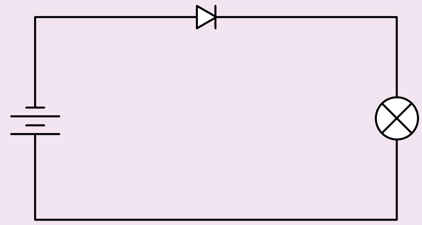


Figure 5.7 *Circuit B*

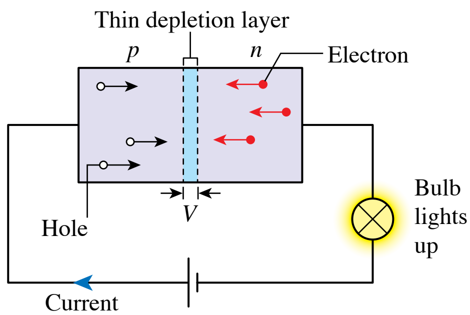
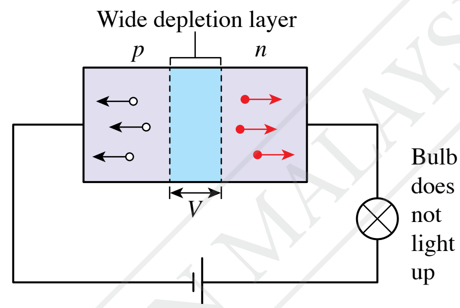
Discussion:

1. What is the function of the diode in this activity?
2. State the condition when a diode allows current to pass through it.
3. If the dry cell is changed to alternating current power supply, what will happen to the bulb?

The Function of a Semiconductor Diode

A semiconductor diode is an **electronic component which allows electric current to flow in one direction only**. A semiconductor diode is formed by joining a p-type semiconductor and an n-type semiconductor to form a p-n junction. Table 5.2 explains the diode connections.

Table 5.2 *Diode connection in a simple circuit*

Forward Biased Circuit	Reverse Biased Circuit
	
When a diode is forward biased, the holes will move towards the n-type semiconductor while the electrons will move towards the p-type semiconductor.	When a diode is reverse biased, the holes and the electrons will both move away from the depletion layer in opposite directions.
Depletion layer becomes thinner.	Depletion layer becomes thicker.
Junction voltage, V across the depletion layer decreases and the resistance of the diode becomes very small.	Junction voltage, V across the depletion layer increases until it reaches the potential difference of the battery. The resistance of the diode becomes very high.
The current passes through the diode, causing the bulb to light up.	The current stops flowing and the bulb does not light up.

Info GALLERY

P-type semiconductors and n-type semiconductors are produced through a doping process, in which foreign atoms are added into a lattice structure of a pure semiconductor. The majority charge carriers for p-type semiconductors are holes whereas the majority charge carriers for n-type semiconductors are electrons. The holes act as positive charge carriers.

The Use of Semiconductor Diode and Capacitor in the Rectification of Alternating Current

Photograph 5.2 shows a smartphone is being connected to an alternating current power supply at home. However, the smartphone can only be charged with a direct current. How does a semiconductor diode convert an alternating current to a direct current?

Photograph 5.2 *A smartphone is connected to an alternating current power supply*

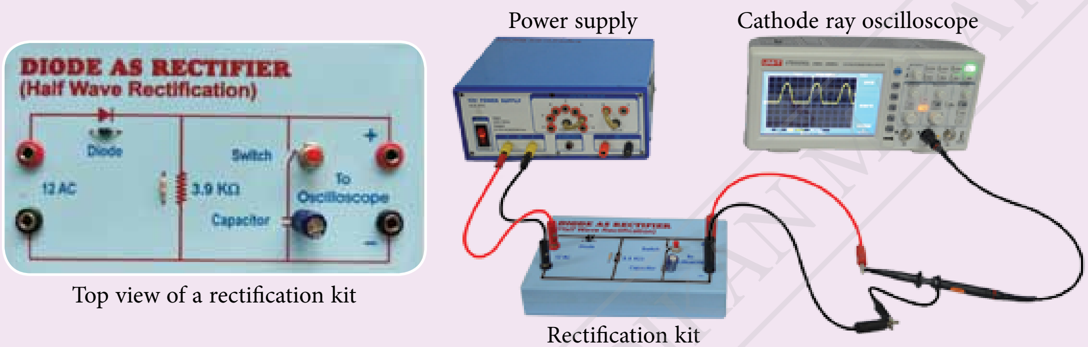
The process of converting an alternating current into a direct current is known as **rectification**. There are two types of rectification which are half-wave rectification and full-wave rectification.

Activity 5.5

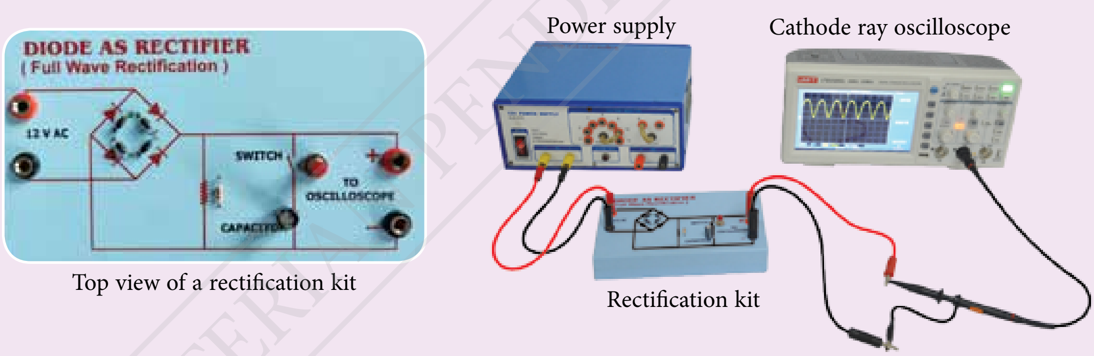
Aim: To build a rectification circuit

Apparatus: Rectification kits, cathode ray oscilloscope, 100 Ω resistor, power supply and connecting wires

Instructions:



Photograph 5.3 *Half-wave rectification kit*



Photograph 5.4 *Full-wave rectification kit*

1. Connect the 100 Ω resistor to a 2 V alternating current power supply. Adjust the cathode ray oscilloscope until a clear sinusoidal waveform appears on the screen. Observe the sinusoidal waveform and record your observation.
2. Connect the half-wave rectification kit as shown in Photograph 5.3. Observe the trace display on the screen and record your observation.
3. Repeat step 2 with the full-wave rectification kit as shown in Photograph 5.4.

Discussion:

State the use of the semiconductor diode in a rectification circuit.

Half-wave Rectification

A complete cycle of alternating current consists of two half cycles: a positive half cycle and a negative half cycle. During the positive half cycle, the semiconductor diode is **forward biased** and allows current to flow through it. During the negative half cycle, the semiconductor diode is **reverse biased** and there is no current flow. This half-cycle rectification process is called **half-wave rectification** as shown in Figure 5.8.

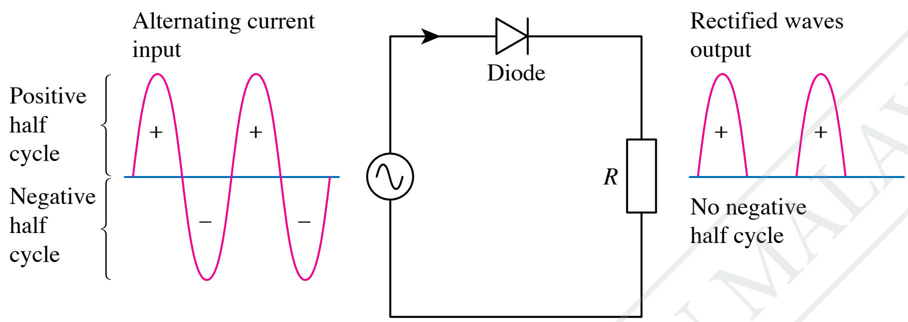


Figure 5.8 *Half-wave rectification*

Full-wave Rectification

The arrangement of four diodes as shown in Figure 5.9 and Figure 5.10 is called a **bridge rectifier**. This arrangement allows a complete cycle of current to flow in the same direction through the load, *R*.

Positive half cycle

- Diodes D_1 and D_2 are forward biased while D_3 and D_4 are reverse biased.
- Therefore, D_1 and D_2 allow current to flow while D_3 and D_4 prevent current from flowing as shown in Figure 5.9

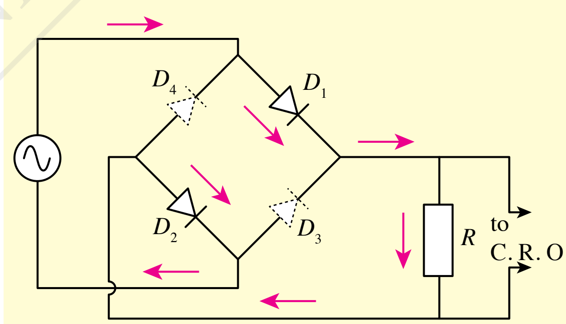


Figure 5.9

Negative half cycle

- Diodes D_3 and D_4 are forward biased while D_1 and D_2 are reverse biased.
- Therefore, D_3 and D_4 allow current to flow while D_1 and D_2 prevent current from flowing as shown in Figure 5.10

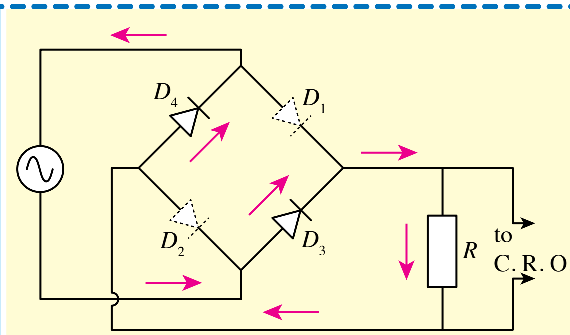


Figure 5.10

Full-wave rectification is a process where both halves of every cycle of an alternating current is made to flow in the same direction. Full-wave rectification displayed on the cathode ray oscilloscope screen is shown in Figure 5.11.

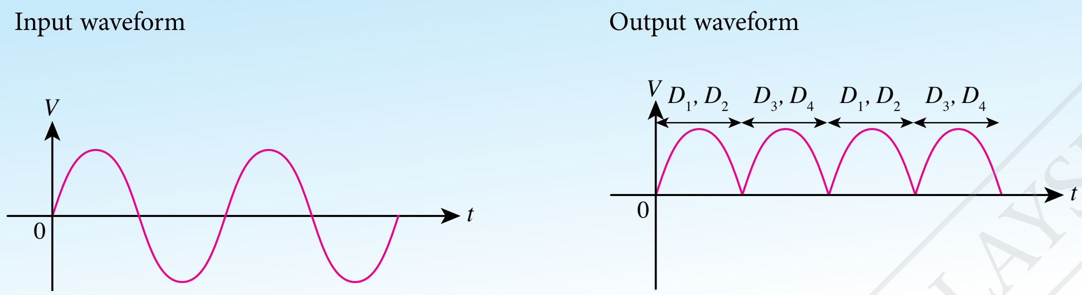
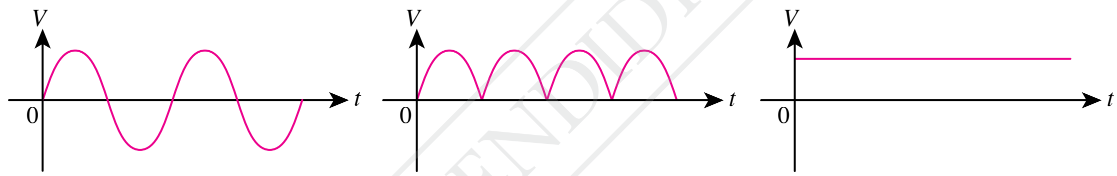


Figure 5.11 *Display of full-wave rectification on the cathode ray oscilloscope*

Info GALLERY

These are several types of currents common in electronic studies. A smooth direct current is essential for a circuit to function well.



(a) Example of an alternating current *(b) Example of a direct current* *(c) Example of a steady direct current*

Capacitors in Smoothing Direct Current

Half-wave and full-wave rectifications produce a direct current which is not smooth. Therefore, a capacitor is used to smooth the current in a rectification circuit.

Activity 5.6

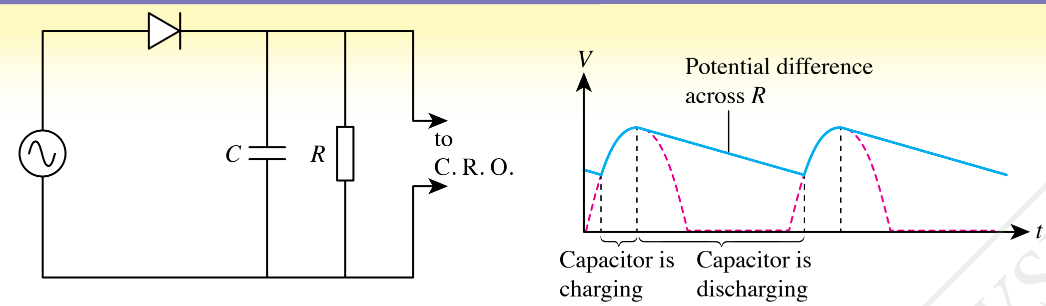
Aim: To collect information on the function of a capacitor in a rectification circuit

Instructions:

1. Carry out the activity in pairs.
2. Collect information related to:
   (a) the function of a capacitor in a rectification circuit
   (b) the factors influencing the effect of current smoothing such as capacitance value and capacitor type
3. You may obtain information from a website or reading resources in the school resource centre.
4. Present your findings.

SCAN ME
Video on capacitors
https://bit.ly/3bfVtDU

Smoothing of Half-wave Rectification Output



Smoothing of Full-wave Rectification Output

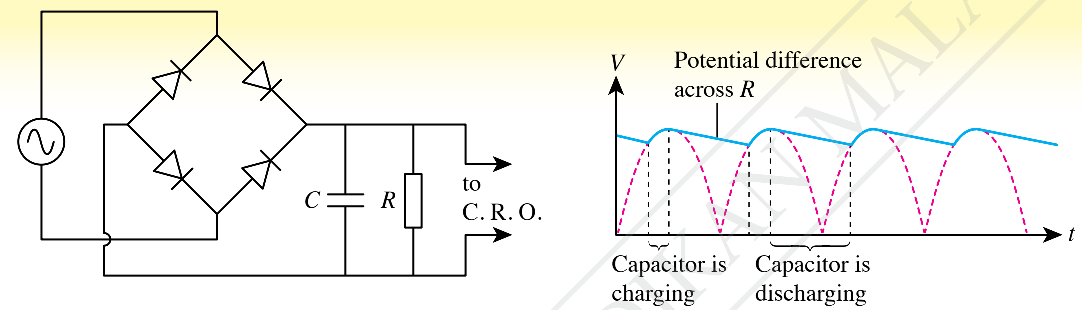


***Figure 5.12** Smoothing of full-wave and half-wave rectification output by a capacitor*

- Capacitor, *C* is connected in parallel to the load, *R*. When the power supply is turned on, the output current becomes smooth.
- When the potential difference increases, the capacitor will be charged and energy is stored in the capacitor.
- When the potential difference decreases, the capacitor will discharge so that the output current does not fall to zero. The energy stored in the capacitor will maintain the potential difference across the resistor, *R*.
- The smoothed output waveform shows that the capacitor is functioning as current smoother.

Formative Practice 5.2

1. What is the meaning of the following terms?
   (a) Semiconductor diode
   (b) Forward biased
   (c) Rectification
2. Draw a full-wave rectification circuit using four semiconductor diodes. Then, sketch the voltage output displayed on the cathode ray oscilloscope if one of the semiconductor diodes is burnt.
3. (a) Name the electronic component that is used to smooth the output current of the full-wave rectification circuit.
   (b) Explain the working principle of the electronic component in 3(a).

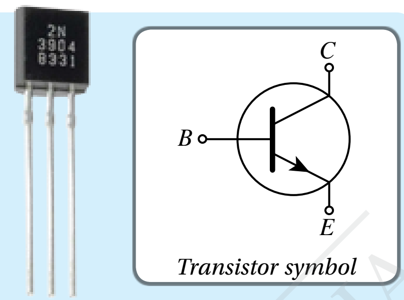
LS 5.2.2

5.3 Transistor

Photograph 5.5 shows a transistor. A transistor is an electronic component that has three terminals, namely emitter, *E*, base, *B* and collector, *C*. What is the function of a transistor?

Emitter, *E* supplies charge carriers to the collector. Base, *B* is a thin layer in the middle of a transistor to control the flow of charge carriers from emitter to the collector. Collector, *C* receives charge carriers from the emitter.

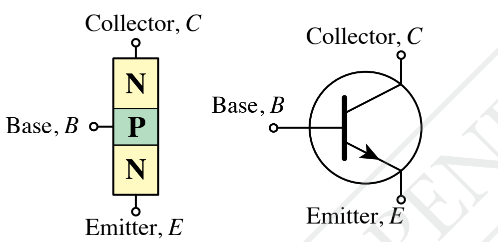
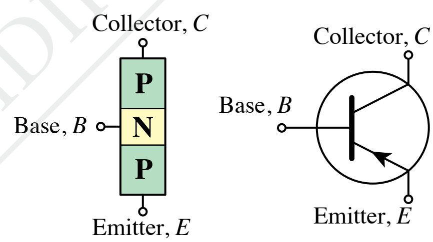
There are two types of transistors: the npn transistor and the pnp transistor as shown in Table 5.3.



Photograph 5.5 *Transistor*

SCAN ME
EduwebTV: Transistor
https://bit.ly/3bdul8w

Table 5.3 *npn transistor and pnp transistor*

npn transistor	pnp transistor
	
The arrow in the symbol shows the direction of current from *B* to *E*.	The arrow in the symbol shows the direction of current from *E* to *B*.

Activity 5.7

ISS ICS

Aim: To collect information on
- npn transistor and pnp transistor
- transistor circuit connected with a npn transistor and a pnp transistor

Instructions:

1. Carry out the activity in groups.
2. Gather information from various reading resources and websites on:
   (a) the terminals of a transistor
   (b) npn and pnp transistors
3. Discuss a transistor circuit based on the following:
   (a) base circuit and collector circuit
   (b) minimum voltage applied to the base circuit of the transistor to turn on the collector circuit
   (c) resistance at the base circuit to limit the base current
4. Present your findings in a suitable mind map.

LS 5.3.1